J. H. Freeman

TOOL-ROOM PRACTICE

PART 5—THE LOCATION OF ACCURATELY SPACED HOLES

MACHINERY'S
YELLOW BACK
— SERIES —

No. 13D

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J. L. Freeman.

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PART 5

MACHINING HOLES FROM CENTRE PUNCH MARKS—LOCATING HOLES WITH BUTTONS AND DISCS—LOCATING HOLES ON A CIRCLE—MISCELLANEOUS METHODS OF HOLE LOCATION

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PREFACE

In previous books on tool-room practice in the *Yellow Back* Series consideration has been given to such fundamental requirements for precise mechanical work as plane surfaces, straight edges and length standards. The methods of measuring available to the tool-maker including micrometers, verniers and slip gauges have also been discussed, and the technique of marking out precision work has been described. The present book is concerned with accurate hole location. This is one of the commonest operations encountered in tool-room work, and, in the absence of modern equipment, affords one of the most exacting tests of the tool-maker's skill. It is for these reasons that the jig boring machine has assumed so important a place in tool-rooms of large and medium size. Appreciating, however, that holes must still frequently be machined accurately to size and with the centre distances held to close limits, without the aid of the jig borer, it has been considered desirable to explain some of the well established methods whereby the desired results may be obtained with a minimum of special equipment. Separate chapters are devoted to the accurate positioning of punch marks and the machining of holes therefrom ; to the use of location discs and tool-maker's buttons ; to the location of holes in the special case when they lie on a common pitch circle ; and to miscellaneous methods which have been devised with the object of enabling the work to be completed more quickly or more accurately than the better known alternatives.

CONTENTS

PAGE

CHAPTER 1

Machining Holes from Centre Punch Marks 5

CHAPTER 2

Locating Holes with Buttons and Discs 24

CHAPTER 3

Locating Holes on a Circle 38

CHAPTER 4

Miscellaneous Methods of Hole Location 49

INDEX 57

CHAPTER 1

MACHINING HOLES FROM CENTRE PUNCH MARKS

At the outset it should be emphasized that where holes are to be bored in a part, such as a die block or jig plate, which must be accurate as regards both diameter and centre distance within close limits, there is no method which can compete with the modern jig boring machine as regards rapidity and convenience. Obviously, therefore, such work should be done on a jig borer wherever a machine of this type is available. There are, however, very many cases where tool-makers, particularly in small tool-rooms, must produce work involving accurately spaced holes without the aid of the jig boring machine. There are various methods by which satisfactory results can be achieved, but, in general, considerable skill is essential to success, and even so the operation is tedious and consumes much time. Jig boring machines will form the subject of a later book in the series, and here it is proposed to discuss some of the alternatives which must be adopted as necessity dictates.

One method, which is perhaps the most elementary, but nevertheless capable of yielding reasonably good results, is to machine the holes directly from centre punch marks. This may be done either at one operation or in stages, with intermediate correction, depending upon the degree of accuracy required. Obviously, the first requirement is that the centre marks should be spaced as accurately as possible. If the marks are to be formed at the intersections of scribed lines produced during the preliminary marking out operation, great care must be taken to ensure that the point of the punch is positioned as closely as possible to the exact point of intersection of the lines. The question was discussed briefly in the companion volume Yellow Back No. 13c, and it was pointed out that the scribed lines should preferably be of symmetrical V shape as produced by a round pointed scriber, rather than of saw-tooth form as obtained when using a chisel point. On account of the difficulty of obtaining an accurate start even with a centre punch of the automatic type, some tool-makers prefer to mark the intersection points initially with a sharp-pointed tool such as a scriber. A small round file, the end of which has been ground to a sharp point, may be used for this purpose, light pressure being applied

while oscillating the file between the finger and thumb. A magnifying glass should be used, as this enables the intersection points to be located much more accurately. The small indentations produced in the manner described are then enlarged with a centre punch, very light blows being struck with a small hammer while the punch is held at right angles to the surface. The punch marks should next be inspected through a magnifying glass to ascertain whether they

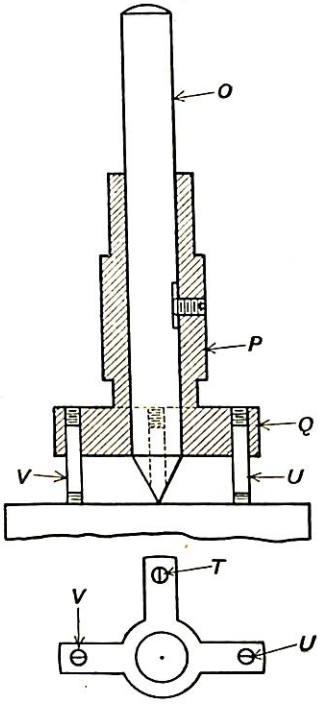


FIG. 1

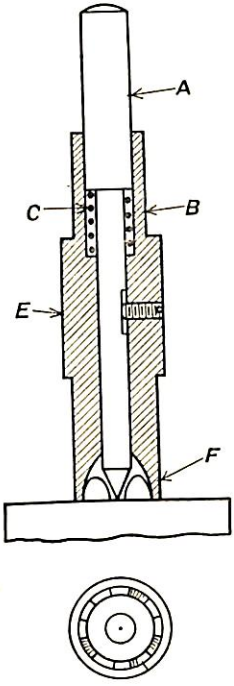


FIG. 2

Fig. 1. Special Punch for Marking the Intersections of Scribed Lines

Fig. 2. Punch for Enlarging Previously formed Centre Marks

are symmetrically located in relation to the marking-off lines. If any mark appears to be slightly off-centre it may be corrected by inclining the punch slightly in the required direction and striking a few light blows. One or two further blows should then be struck with the punch once more in the vertical position.

Fig. 1 shows a special type of punch which has been developed to facilitate the accurate marking of intersections and is claimed to give very good results in service. The small centre punch *O*

is accommodated in a holder *P* which is knurled on the outer surface to facilitate handling, and the 60-degree point must be accurately ground true with the axis. The holder stands on three legs, as shown, which must be a tight fit in their ho'es to prevent them from turning. Small screws being used for backing up purposes. It is essential that when the three legs are resting on the surface of the work, the axis of the punch should be accurately positioned at right angles thereto. The legs terminate in sharp chisel points, the included angle of which should be slightly less than that of the scriber point used for marking the lines. The corners should be rounded slightly to ensure that the legs will slide smoothly along a line. The edges of two of the legs, for example *V* and *U* must be in the same plane which also contains the axis of the punch. The edge of the other leg *T* must lie in a plane which contains the axis of the punch and is at right angles to the plane of the legs *V* and *U*. It will be apparent that, providing these conditions are fulfilled, when the edges of *V* and *U* are resting in one scribed line, and the edge of *T* in the line at right angles thereto, then the point of intersection of the lines must be on the axis of the punch.

In operation the edges of the legs *U* and *V* are allowed to rest in the minute groove formed by one of the marking out lines and are slid along until the edge of the leg *T* drops into the other line which is at right angles to the first. The punch *O* is raised clear of the surface while the legs are being located in the required positions, and is retained by means of a leather friction pad engaged by a set screw in the side of the member *P*. Only a very light blow should be struck sufficient to produce a small mark on the work. If the best results are to be obtained, a smooth surface should be provided on the work prior to scribing the lines. It is also desirable to remove the slight burr thrown up by the scribing point by rubbing lightly with an oil stone. Finally a little oil should be rubbed into the lines and the surplus wiped off. In this way it is ensured that the edges *U* and *V* will slide smoothly along one line, and that the edge *T* will readily drop into the other.

For enlarging the small indentation produced by the tool in Fig. 1, the follower punch shown in Fig. 2 may be employed. Here again the punch is accommodated in a holder so that it is automatically located at right angles to the work surface. At the lower end the holder is cut away to form four legs, as at *F*, so that an unobstructed view of the punch point may be obtained. The punch is normally held in the raised position by the spring *C*, its movement in relation to the holder being limited by the end of a set screw. After the point of the punch has been located in the mark a number of light blows may be struck so as to produce an indentation of the required size.

Locating Block for Centre Punch

In Fig. 3 is shown a combination centre punch and locating block which can be used in conjunction with slip gauges and end measuring bars, the marks produced being positively positioned within close limits. The block is made from tool steel, hardened and ground, the hole being lapped to a close fit for the punch which is also finished by grinding and lapping. The four sides are ground true and the lower face squared up with the block mounted on an arbor. The distance between the centre of the hole and the side

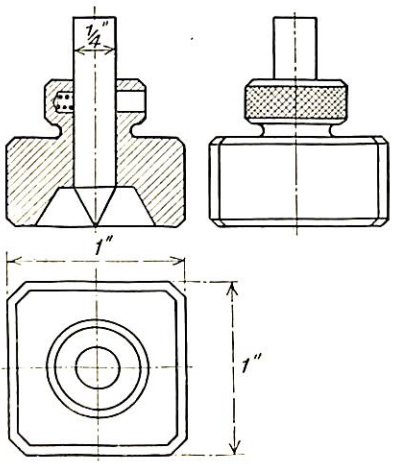


Fig. 3. Combination Centre Punch and Locating Block

must be held to some convenient dimension, say $\frac{1}{2}$-inch, within very close limits. The round upper part of the block is knurled to give a good grip for the fingers. The punch may be made of hardened tool steel and the point must, of course, be ground accurately concentric with the body. The head end should be bevelled, as shown and may with advantage be tempered so that it is a little softer than the remainder.

The method of marking out hole centres with the locating block will be clear from Fig. 4. The work *A* is first ground to provide a flat surface after which two straightedges *B* and *C* are accurately located at right angles to one another and clamped in position. These straightedges serve as datum faces from which to locate the punch marks at *D*, *E* and *F*. The block is shown in position at *G* for forming the punch mark *D*. To locate the punch point at a distance of 3 inches from the straight-edge *B*, a $2\frac{1}{2}$-inch slip gauge combination is employed. Similarly, to locate the point at a distance of 5 inches from the straight-edge *C*, the length of the measuring

bar *H* and the slip gauges used in conjunction therewith must total $4\frac{1}{2}$ inches. Slip gauges may, of course, be employed for obtaining the required settings in relation to both straight-edges, and it is essential that they should be used for at least one of the settings to ensure that the block is properly squared up. When the block has been positioned, as required, light pressure is applied to keep it in contact with the slip gauges, or with the slip gauges and end measuring bar as the case may be, and the head of the punch is tapped to produce a mark on the work. This may later be enlarged

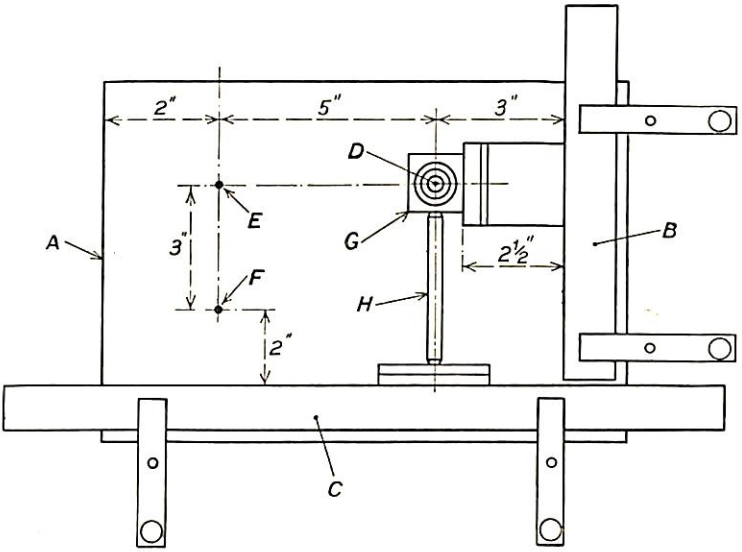


Fig. 4. Method of Marking out Hole Centres with the Combination Punch and Locating Block

with a punch of the type shown in Fig. 2. Instead of using two straight-edges as shown in Fig. 4 a machinist's square may sometimes be employed with advantage. Where a series of holes is to be located in a straight line it is only necessary to use one straight-edge together with a pin or block which can be clamped to the work to provide an abutment for measuring.

As an alternative to the square locating block the punch may be accommodated in a round holder the outside diameter of which is concentric with the bore. Such a holder is easier to produce to the close limits of accuracy required but is not quite so convenient in use as the square type.

The Use of the Milling Machine for Marking Hole Centres

If a milling machine is available in good condition, and with micrometer dials on the feed screws for the longitudinal and transverse table movements this may sometimes be pressed into service to facilitate the location of hole centres. The work is

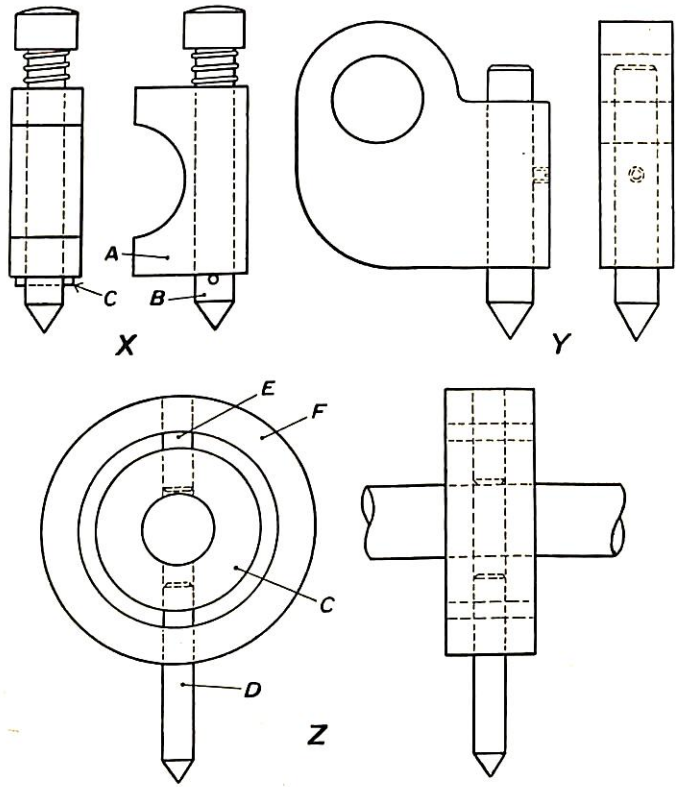


Fig. 5. Punch Holders for Use when Marking Out Hole Centres on a Milling Machine

mounted on the table, and if it takes the form of a rectangular block, the edges should be aligned with the directions of table movement. A punch holder of suitable form is then secured to the horizontal arbor of the machine so that the axis of the punch is at right angles to the plane of the work surface. Next the table is adjusted until the position of one of the required centre marks

on the work is vertically below the punch point. This centre should have been previously marked off by scribed lines, and should preferably have been punched by the methods already described to facilitate accurate location. When the table has been set, the readings of the micrometer dials on both screws are noted, and it is then a simple matter to adjust the table longitudinally and transversely so as to bring the various hole centre positions successively beneath the punch point. After each setting has been made the punch is lightly tapped to mark the work. The final direction of rotation of each screw should always be the same as when obtaining the initial setting in order to eliminate the effects of any backlash that may be present.

A simple form of punch holder which can readily be clamped in position between spacing collars on the arbor of the machine is shown at *X* in Fig. 5. The body *A* may be made from machine steel and case-hardened. It is bored to receive the punch and is formed with a half round groove to suit the arbor diameter. The punch *B*, which is made from tool steel, hardened, ground and lapped, is normally held in the raised position by a light spring, as shown, the upward movement being limited by the pin *C*.

Another type of punch holder is shown at *Y* in Fig. 5. Here the body is bored to suit the machine arbor on which it is clamped between spacing collars. The punch should be a good fit in the hole provided for its reception so that it will remain in any position and not fall under its own weight. A small brass screw serves to take up any slight wear which may occur.

At *Z* in Fig. 5 is shown a somewhat different arrangement which permits of scribing layout lines in addition to marking centres. The collar *C* should be a good fit on the milling machine arbor and when in use is clamped in position. It is provided with transverse holes in which the ends of the scriber *D* and the guide pin *E* are close sliding fits. The scriber is a tight fit in the outer ring *F* as also is the pin. This outer ring serves as a weight to apply the necessary pressure to the scriber point for marking the lines. In operation, with the spindle locked in position, the table is first adjusted as required by turning the longitudinal or transverse screw and is then raised until the pin *E* is lifted clear of the arbor so that the weight of the outer ring is supported on the scriber point. Lines may then be scribed by traversing the table as required. For marking centres the top of the ring may be lightly tapped with a hammer after the work has been correctly adjusted in relation to the scriber point.

Guide Circles and Square

When holes are to be produced from punch marks, it will be obvious that as soon as machining commences the marks are lost. Particularly if the work is to be done on a drilling machine, however,

it is desirable that the tool-maker should have some indication, while the operation is in progress, as to whether the centre of the hole is, in fact, coincident with that of the punch mark originally provided. For this reason it is customary to provide guide squares or circles before beginning to machine the work. Thus a guide circle may be scribed with a pair of dividers one point of which is located in the centre punch mark. The radius of this circle should correspond with that of the finished hole. Suppose now that a hole is drilled of a diameter somewhat smaller than that required and that the centre of this hole is displaced by an amount *a*, shown greatly exaggerated at *X* in Fig. 6, from the centre of the punch mark. The eccentricity of the hole, shown dotted, in relation to the scribed circle will then be clearly apparent since the difference

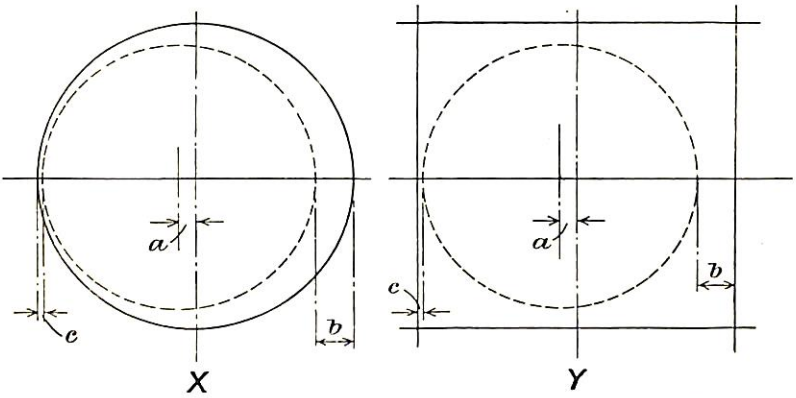


Fig. 6. Diagrams Illustrating the Use of Guide Circles and Squares to Indicate Errors in the Position of Drilled Holes

between the distances *b* and *c* is twice the error *a*. An opportunity is thus afforded of restoring concentricity by the use of scraper or file before opening out the hole to the final diameter with the aid of a drill or reamer of appropriate size.

The guide square shown at *Y* in Fig. 6 fulfills the same purpose as the guide circle. It is marked with the scriber point of the height or surface gauge while the work is set up for marking the centre lines the sides of the square being parallel to these centre lines and at a distance therefrom equal to the radius of the required circle. In practice it is somewhat easier to correct a hole so that it is concentric with a scribed circle rather than to ensure that it is symmetrically disposed within a square. Nevertheless the method shown at *Y* in Fig. 6 offers certain advantages. The square can be positioned with a high degree of accuracy in relation to the centre lines provided that the marking out operation is carefully

performed. The positioning of the guide circle, on the other hand, depends upon the accuracy with which the punch mark has been located in respect to the intersection of the centre lines and, as previously explained, the introduction of a slight error is difficult to avoid. When working to a circle, moreover, there is a risk that part of the outline may be lost due to the burr thrown up by the drill. If this happens, correction becomes more difficult. With a guide square on the other hand only small portions of the lines will be lost on one or two sides and it is relatively easy to judge the position of the hole in relation to the remaining portions of the lines.

It will be apparent that the more closely the drilled hole diameter approaches that of the scribed circle or the side length of the square, the more accurately can the correction be made. Where a hole is to be machined in several stages, therefore, it may be desirable to provide a series of guide circles or squares.

Checking the Spacing of Punch Marks

Regardless of the care which is taken in marking out, it is desirable to check the spacing of the punch marks before machining is commenced, particularly if accurate results are required. Dividers may be used for measuring the distances between the various marks, but this method is not particularly reliable owing to the risk of the legs being sprung slightly. Better results can be obtained with the aid of the simple indicator shown in Fig. 7 which is intended to replace one of the legs of the ordinary trammels or beam dividers. The body of the indicator is arranged for clamping to the beam by means of a knurled nut and at the lower end is a screw on which the pointer *A* pivots. The pointer is made from thin spring steel stock, the lower end being tapered and the point rounded slightly as seen in the enlarged view at *X*. The included angle of the taper should be slightly less than that of the punch used to produce the marks. For example if the punch has an angle of 60 degrees, the angle of the point should be approximately 50 degrees, as indicated. The spherical point then rests in the cone of the punch mark and a true reading is ensured.

The screw for the clamping nut is extended and carries a small segment *B* provided with graduations in conjunction with which the position of the upper end of the pointer is determined. The pivot axis should preferably be so positioned in relation to the length of the pointer and the graduation lines so spaced, that a movement from one line to the next corresponds to a displacement of 0·001-inch of the lower end which enters the punch mark. Stop pins *C* at the ends of the segment limit the movement of the pointer, and a piece of music wire *D* inserted in the body of the indicator acts as a light spring whereby the pointer is normally centralized in relation to the graduations.

A convenient form of setting gauge is shown at *Y* in Fig. 7. It consists of a bar *E* to the ends of which supporting blocks are secured by screws. The block *F* is fixed at one end of the bar, while the block *G* can be adjusted to any desired position and

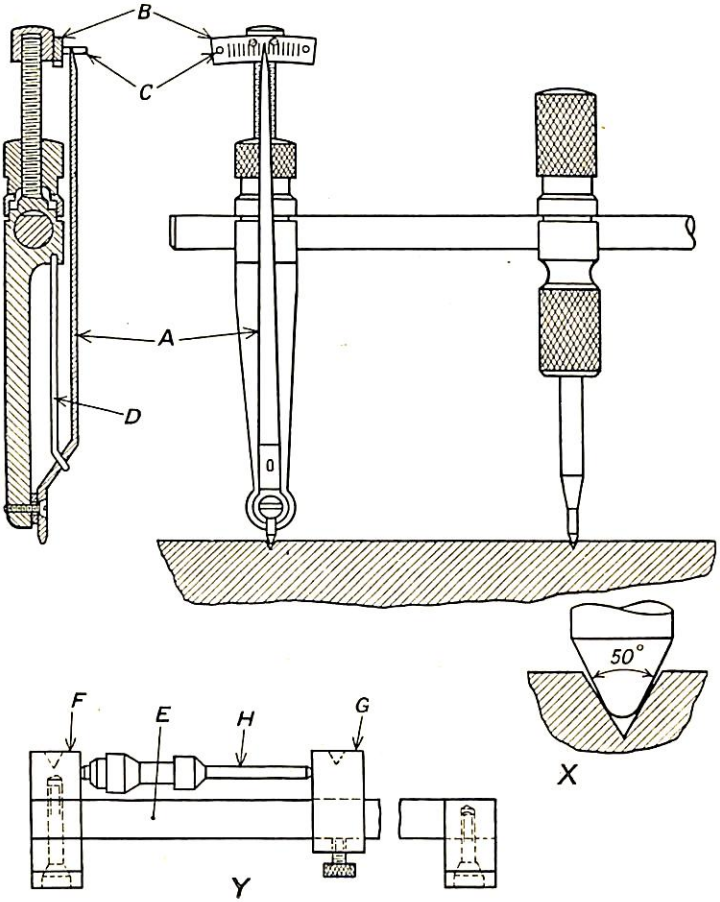


Fig. 7. Indicator for Use when Checking the Spacing of Punch Marks and Method of Setting

clamped by means of a knurled head screw. The blocks *F* and *G* have conical depressions in the upper surfaces corresponding to the punch marks to be checked, the centres of the depressions being at some convenient known distance from the inner faces of the blocks. With the aid of an internal micrometer indicated

diagrammatically at *H*, the blocks may be set so that the centres of the depressions are at the required distance apart. The trammels are then adjusted so that, with the ends of the standard leg and of the indicator pointer resting in the depressions, the pointer is opposite the zero mark on the scale. The trammels are next applied to the work as indicated in the main view in Fig. 7, and if there is any error in the spacing of the punch marks the pointer will be deflected from the central position. Where there are a number of marks it is usually possible by taking a series of readings between different

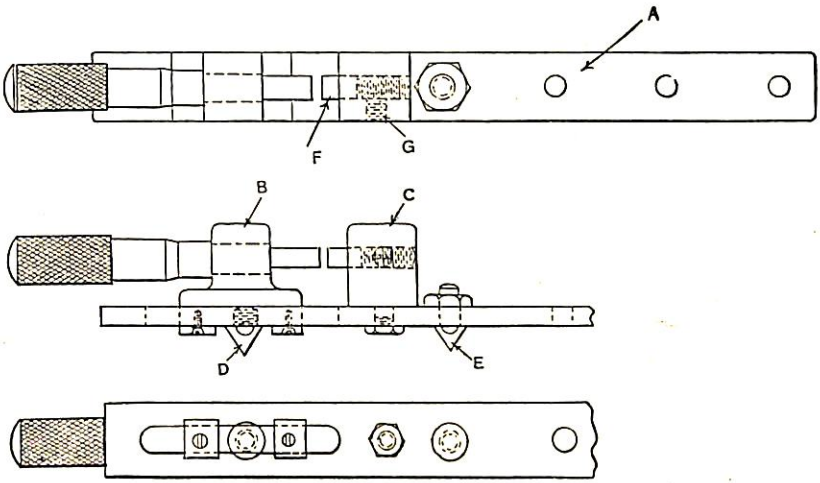


Fig.8. Special Micrometer for Measuring the Distances Between Centre Punch Marks

pairs, to determine which are incorrectly positioned and also the directions of the errors. Correction may then be effected by striking light blows with the centre punch inclined, as previously explained.

Another device for measuring between centre punch marks is shown in Fig. 8. The body *A* is made from tool steel, as are the members *D* and *E*, the latter being hardened and ground to give conical points of 60-degree included angle. For the members *B* and *C* machine steel may be used. The member *C* is secured in position on the member *A* and carries an adjustable stop or anvil *F*, which can be locked after setting by means of the grub screw *G*. The member *B* carries a micrometer head having a range of adjustment of 1-inch. It is provided with a tongue which is a close sliding fit in a slot in the member *A*. The centre *D* is screwed into the member *B* and two small plates are attached thereto by screws. These plates bear on the lower face of the member *A*, and when the

device is assembled the member *B* should be free to slide in its slot but there should be no vertical or lateral play. A series of holes spaced exactly 1 inch apart is provided in the member *A* for the reception of the shank of the centre *E*. The first of these holes should be so positioned that, when the member *E* is located therein and the end of the micrometer spindle is in contact with the anvil, the instrument being set at zero, the two points are exactly 2 inches apart, this being the minimum distance for which the device is designed.

In use, the centre *E* is positioned in the appropriate hole and the member *B* is adjusted until the two centre points will accurately engage two centre marks in the work. The micrometer spindle is

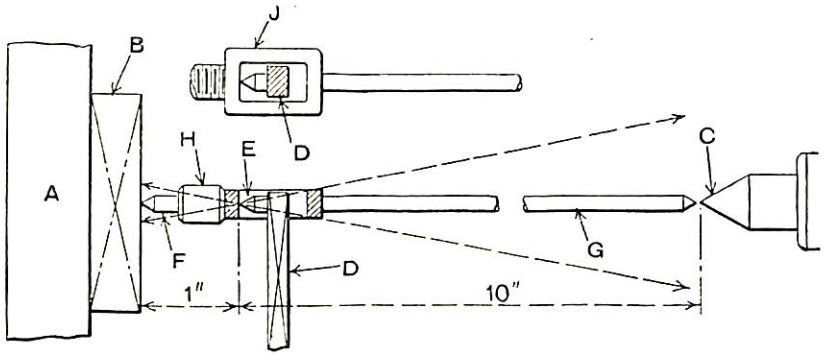


Fig. 9. A Simple form of Wiggler for Use when Setting Work on a Lathe Faceplate

then advanced until it engages the end of the anvil *F* and a reading is taken. This gives the decimal part of the dimension which must be added to the known whole number of inches to obtain the distance between the punch marks.

The device can also be used sometimes to facilitate marking out. In this case the points are first adjusted to the required distance apart, after which a light blow is struck above each centre with a hammer. The small indentations thus produced in the work can subsequently be enlarged.

Wigglers or Indicators for Punch Marks

After the centre punch marks have been formed in the required positions and the distances between them have been checked, the part must be set up on the machine so that the centre of one of the marks coincides with the axis of rotation of the work or tool spindle according to whether the operations are to be performed on a

lathe, or a milling or drilling machine. To facilitate setting it is customary to employ some form of indicator or wiggler as it is commonly termed.

A simple form of wiggler for use when setting work on the lathe face-plate is shown in Fig. 9. Here *A* represents the face-plate and *B* the block in which a hole is to be machined from a previously formed punch mark. The work is first adjusted until the centre mark is approximately on the axis of rotation, as determined by turning the face-plate by hand, the tailstock centre *C* being brought close to the work surface to serve as a guide. The tail-stock centre is then withdrawn and the indicator mounted in position. It comprises a long rod *G* terminating in a rectangular portion *J* with an opening which accommodates the end of the rod *D* and the hardened centre *E*. An extension to the left of the

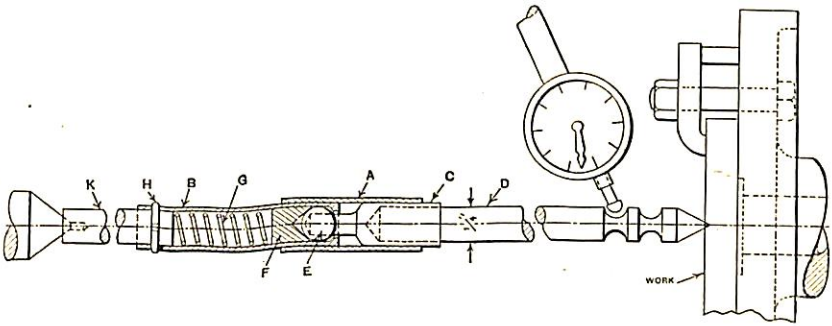


Fig. 10. Another Design of Wiggler for Use on a Lathe or Drilling Machine

member *J* is bored to receive the shank of the centre *F* which should be a good sliding fit in the hole. A small compression spring inserted in the bottom of the hole tends to force the centre *F* towards the left, the movement being limited by the retaining sleeve *H* which is screwed on to the extension of the member *J* and engages a shoulder on the shank of the centre.

The bar *D* is held in the tool-post of the lathe and the centre *E* engages a centre hole formed in the side of the rectangular opening. In operation the point of the centre *F* is engaged with the punch mark in the work, and the bar *D* carrying the centre *E* is set so that the spring is slightly compressed. The indicator is thus supported by the two centres. When the face plate is turned the indicator does not rotate on its axis, but if the centre of the punch mark in the work does not coincide with the spindle axis the indicator is caused to pivot about the point of the centre *E*. The two ends of the indicator thus describe circles the diameters of which are

in the same ratio as the lengths of the lever arms. Suppose, for example, that the distances from the point of *E* to the ends of the indicator are 1 and 10 inches, and that the centre of the punch mark in the work is displaced by 0·001-inch from the spindle axis. Then the point of the centre *F* will describe a circle of 0·002-inch diameter, and the point of the long rod *G* a circle of 0·02-inch diameter. The work should be adjusted until the end of the rod *G* appears to remain stationary when the face-plate is turned. If the tail-stock centre is brought close to the point of the rod, any appreciable movement is made clearly apparent. It is not essential that the point of the centre *E* should be located exactly on the line of centres but it should be positioned with reasonable accuracy.

It should perhaps be mentioned that if the work is of irregular form the face-plate should be balanced, and a test made to ensure that the centre mark runs true when the spindle is rotating at the same speed as that which will be employed for the boring operation.

Another form of wiggler for use on the lathe is shown in Fig. 10. The member *K* is formed with a centre hole for the reception of the tail-stock centre point and is a press fit in the tube *B* to which it is secured by the pin *H* after the parts have been assembled. The member *F* which has a conical depression forming a bearing for the ball *E* is a sliding fit in the tube *B* and is backed up by the spring *G*. The member *F* and the ball *E* are hardened, and withdrawal of the latter is prevented by a shoulder at the end of the tube *B*. The member *C* has a shank which is a press fit in a hole in the ball, while the shank of the centre *D* is a press fit in the member *C*. The outer surface of the sleeve *A* is knurled and the bore is made a sliding fit on the tube *B* and the member *C*. Thus with the sleeve in the position shown these parts are held positively in alignment.

With the hardened point of the centre *D* engaging the punch mark in the work the latter is adjusted until the centre runs true, the tailstock being set in such a position that the spring is slightly compressed. A dial indicator mounted on the tool-post and with the contact point engaging one of the grooves in the member *D* serves to show when the desired setting has been obtained.

This type of wiggler may also be used on a drilling or milling machine where the tool spindle rotates and the work remains stationary. In this case the sleeve *A* is moved back on to the member *B* so that movement can take place at the universal ball and socket joint. The member *K* is gripped in a chuck carried by the machine spindle. Alternatively it may be provided with an external tapered surface so that it can be inserted in a taper socket. When the spindle is rotated, the member *B* runs true, but if there is any error in the position of the punch mark the member *D* oscillates slightly about the centre of the ball *E*. The dial indicator may be carried by a universal holder resting on the machine table or the work surface, or mounted in any other convenient manner. As

before, the contact point is brought into engagement with one of the grooves in the member *D* but in this case only just sufficient pressure must be applied to ensure a positive reading otherwise the member *D* may be prevented from rotating with the member *B*.

It should, perhaps, be pointed out that when the indicator is used in this manner, the contact point of the dial indicator should be applied to the member *D* as near as possible to the end which is in engagement with the work. In this way, the effect of any error in the position of the centre of the ball *E* relative to the machine spindle is minimized.

An indicator of a different type is shown in section in Fig 11. The shank *I* is made either taper or parallel, depending upon the

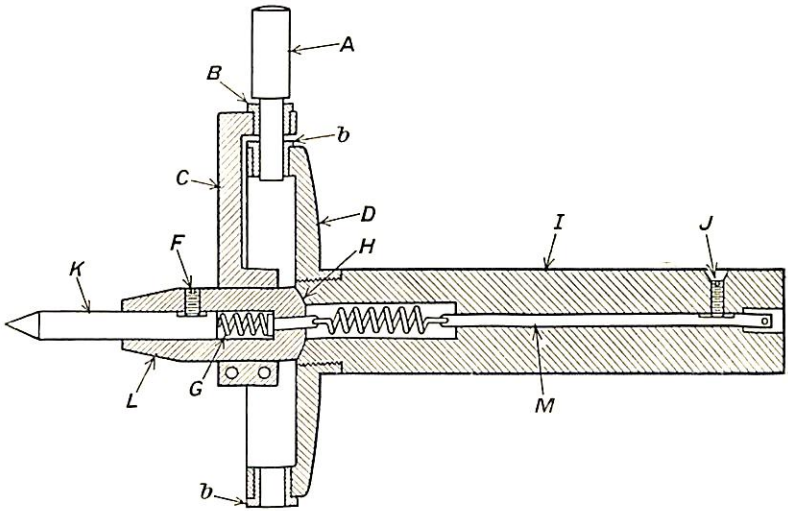


Fig. 11. Indicator for the Accurate Location of Punch Marks when Setting Work on a Milling Machine

manner in which it is to be mounted when in use, and is provided with a threaded nose for the reception of the disc *D*. Four equally spaced holes are provided in the rim of this disc in which hardened, ground, and lapped bushings *b* are inserted. The plug *A* is made a close sliding fit in these bushings and also in the bushing *B*, which is inserted in a hole at the outer end of the arm *C*. This arm is secured by a split sleeve to the barrel *L* which carries the rod *K*, the latter having a point for engaging the punch mark in the work. The spherical end of the barrel *L* fits into a corresponding concave seating in the nose of the arbor at *H* and is held in position by a tension spring. This spring is anchored at one end to a stud inserted in the barrel *L* and at the other to the rod *M*. An axial

hole in the shank accommodates the rod which is secured in position against the pull of the spring, by the headless set-screw *J* engaging a small flat, as shown.

If the plug *A* is withdrawn, the point of the member *K* may be brought into engagement with a punch mark in the work, even though the latter is not positioned correctly in relation to the machine spindle. To effect such engagement, the barrel *L* must be tilted slightly on its spherical seating, so that its axis is no longer in alignment with that of the shank *I* which is held in the machine spindle. The arm *C* is also tilted so that the axis of the bushing *B* is no longer positioned radially in relation to the shank axis. Under these conditions it is obvious that the plug *A* cannot be passed through the two bushings *B* and *b* with the arm *C* in each of the four positions. The work must therefore be adjusted until the plug will freely enter the corresponding bushing *b* with the arm in any position. It is then known that the centre of the punch mark lies on the extension of the spindle axis. A groove in the rod *K* engaged by a set screw *F* permits of slight axial movement of the rod as the work is adjusted while the spring *G* holds the point in engagement with the punch mark.

In practice it has been found desirable to form the point on the rod *K* to a slightly smaller included angle than that of the punch used for producing the centre mark. In this way there is less risk of the centre mark being drawn from its true position while the work is being adjusted. When using this indicator, neither the work nor the machine spindle is rotated, but only the barrel *L*, the strength of the spring *G* being so selected that it does not interfere with the free turning of the barrel on its seating.

The indicator may be employed for setting work on a lathe face-plate but it is primarily intended for use on a horizontal milling machine. It should preferably be mounted so that the axes of two of the bushings *b* are at right angles to the plane of the table surface, the axes of the remaining holes being parallel to this plane. After the work had been located in the manner described, the gibs of the machine should be tightened up, and a final check made to ensure that the knee has not moved sufficiently to introduce any perceptible error. The table is then clamped in position, and the work is drilled and bored to the required diameter.

Machining the Holes

If the holes are to be machined on a lathe face-plate, once the centre marks have been accurately positioned no particular care need be taken during the drilling operation, since any tendency of the drill to run can later be corrected by the single-point boring tool employed for finishing. If, however, the work is to be performed on a drilling machine for example, and the initially drilled hole is required to serve as a guide for the tools to be employed for opening

it out to the required diameter, then precautions must be taken when starting.

For parts demanding no very great degree of accuracy, holes may be drilled direct from the punch marks at one operation. The centres should be deeply punched and a short taper-shank drill employed. The drill should be ground so that the point angle is the same as, or very slightly less than that of the centre punch, and the cutting edges are of equal length. The drill may be tried in some scrap material to ensure that the hole produced is of the required diameter within the limits permitted.

To obtain a higher degree of accuracy a preliminary countersinking operation may be performed. A flat drill, made from drill

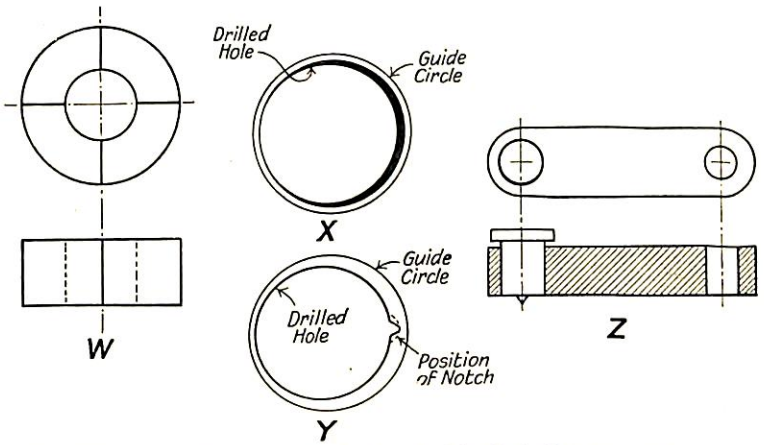


Fig. 12. W-Disc for Locating Spotting Tool in Relation to Scribed Lines. X—Method of Correcting Hole by Scraping. Y—Diagram showing Position in which Correcting Notch is formed Prior to Reaming. Z—Simple Guide Plate for Machining Holes from Punch Marks

rod, and ground to the angle of the centre punch, will be found satisfactory for this purpose. If a twist drill is employed it may be desirable to reduce the lip angle slightly so that there is a tendency to rub rather than to cut too keenly. In this way the possibility of chatter is reduced. The operation may be interrupted and observations made to ensure that the countersink is correctly positioned in relation to the marking off lines, or to a guide circle of small diameter. Slight errors may be corrected by further centre punching. If the error is too great to be eliminated in this way, a disc of the form shown at *W* in Fig. 12 may be employed. This has a hole to suit the external diameter of the countersink and should preferably be hardened. Lines are scribed at right angles on the upper surface of the disc which would intersect at the axis of the

hole, and are extended down the sides, as shown. The disc may thus be so positioned on the work that the centre of the hole is vertically above the original point of intersection of the marking off lines. It is then secured by a clamp of suitable form and the tool is fed down through the hole so that it will cut away the faulty centre and bring the countersink into the correct position. Some tool-makers claim that with careful countersinking followed by drilling they can obtain holes which are accurately located within ±0·001-inch.

A further refinement involves the drilling of a hole of smaller diameter than that finally required, the position of which can be checked and corrected using a round file, or a half-round or 3-square scraper. The correction may be carried out with reference to guide squares or circles, as previously explained. Alternatively, after all the holes have been rough drilled the distances between them may be measured with the aid of vernier calipers, and, the diameters of the holes being known, and errors in the centre distances may be determined. Another method involves the use of plugs which are a close fit in the holes and over which measurements may be taken with micrometer, vernier calipers or height gauge. Care is necessary when correcting a hole with file or scraper to ensure that the metal is so removed as to eliminate the error and establish concentricity with the guide circle, as seen at *X* in Fig. 12, the use of a magnifying glass being recommended. Having ascertained the amount of metal which must be removed, the work may be checked for size and roundness, as the operation proceeds with a small pair of tool-makers inside calipers set with a micrometer. Alternatively the hole may be scraped to fit a previously prepared plug of the required size.

A hole thus corrected is sometimes opened out to the final dimension with the aid of a larger size of drill. It is difficult to obtain good results in this way, however, because, when the lips of the drill engage the sharp corner of the hole, there is a tendency to chatter. In general, therefore it is preferable to employ a reamer for this operation. The blades of the reamer should be ground or stoned to produce a slight taper extending over a length of about ½-inch at the front end, the small diameter being made equal to that of the drilled hole. In this way centring of the reamer in the hole is facilitated and a good finish is ensured. Care should be taken to ensure that the reamer runs true in the machine spindle. The work should preferably be supported on parallels so that it is free to float during the operation, being held by hand to prevent rotation. In this way the risk of producing a bell-mouthed hole is reduced. A slow spindle speed and a light hand feed should be employed with a copious supply of oil to the reamer.

When a hole is subsequently to be sized by reaming the work of correction may sometimes be facilitated by filing a very small notch at one side using a 3-cornered file. This notch may afterwards be opened out slightly with a round file, as indicated diagrammatically at *Y* in Fig. 12. The presence of such a notch tends to draw the reamer slightly with the result that the reamed hole is somewhat eccentric in relation to the drilled hole, the notch being, of course so located that the hole centre is displaced in the required direction. When employing this method the hole should be drilled about $\frac{1}{64}$inch under size. Until experience has been gained moreover it is advisable to employ an under-size reamer so as to provide an opportunity for further slight correction before the hole is opened out to the required diameter.

In certain cases it may be found preferable to produce an accurately positioned hole by drilling and reaming in the manner described, this hole then being used to guide the pilot of a pin cutter or counterbore of appropriate diameter.

Another method of drilling holes from centre punch marks involves the use of the simple equipment shown at *Z* in Fig. 12. A steel plate *A*, of the form shown, is first prepared, the upper and lower surfaces being ground and two holes drilled and reamed to diameters slightly less than those of holes to be machined in the work. For convenience the sizes of the holes may be stamped on the surface of the plate, which is then hardened, the holes subsequently being lapped out to the exact diameters required. Plugs such as that shown at *B*, with small 60-degree centre points are then made from drill rod, hardened, ground and lapped to fit the holes. The points should also be lapped accurately concentric with the bodies.

With a plug inserted in one of the holes in the plate, the point is brought into engagement with a centre punch mark in the work. The plate is then clamped securely in position and the plug removed. The hole in the plate now serves as a guide bush through which the work may be countersunk, drilled and finally reamed to size.

In general it is preferable to employ a lathe, if possible, for machining holes from punch marks. In this way the operation can be carried out fairly rapidly with reasonably accurate spacing, and without the aid of special equipment. There is, moreover, less risk of introducing errors in parallelism of the hole axis, than if the work is performed on a drilling machine.

CHAPTER 2

LOCATING HOLES WITH BUTTONS AND DISCS

Where holes must be located within close limits of accuracy, for example, for the reception of drill guide bushes in a jig plate, and no jig boring machine is available, very good results can be obtained by the use of the so-called button method. The main disadvantage attaching to this method lies in the fact that, particularly where the number of holes is large, the time occupied in setting the buttons is excessive, even when the tool-maker is highly skilled. There is no doubt, however, that a very high degree of accuracy can be obtained in this way. The normal toolmaker's button takes the form of a small cylindrical bush which should preferably be made from tool steel and hardened. The outside diameter should be accurately ground to some convenient dimension so that allowance can conveniently be made when taking measurements. The ends of the bush should be ground accurately at right angles to the axis. A suitable size of bush is one having an outside diameter of 0·4 or 0·5-inch and an inside diameter of 0·3 or 0·4-inch. The length may, with advantage, be from $\frac{3}{4}$ to $\frac{7}{8}$-inch. If the bush is too short, difficulty may be experienced in applying an indicator when setting up the work on a lathe or milling machine in a manner subsequently to be explained.

The usual form of button is seen in section at *A* in Fig. 1 which also indicates the method of securing it in position by means of a screw engaging a tapped hole in the work and a washer. It will be observed that clearance is provided between the screw and the bore of the button so that the setting of the latter can be adjusted as required. Should it be required to locate two holes close together by means of buttons, it would be found difficult or impossible to set the work on the machine with the aid of an indicator if both buttons were of equal length. Under these conditions if an attempt were made to rotate the work or tool spindle of the machine with the contact point of the indicator in engagement with the periphery of one of the buttons, the second button would foul the indicator. One method of overcoming this difficulty is to employ buttons of different lengths as seen at *A* in Fig. 1. The work is then first set for machining the hole located by the longer button, to the projecting end of which the indicator is applied. After the setting has been obtained the long button

is removed and the hole bored, thus leaving the way clear for the application of the indicator to the second button when making the second setting. Alternatively, buttons of the form shown at *B*, Fig. 1, may be used for closely spaced holes. Here, it will be observed, the button is counterbored to receive the head of the retaining screw. The counter-bored hole is ground accurately concentric with the outside diameter so that the indicator point can be applied to the bore instead of to the external surface of the button, thus eliminating the possibility of interference.

Positioning the Buttons

When a series of holes is to be located by the button method, the positions of the various centres are first marked out and punched in the manner explained, and circles are drawn to suit the diameter of the buttons to be employed. The centre marks should be positioned with reasonable care, but no very high degree of accuracy

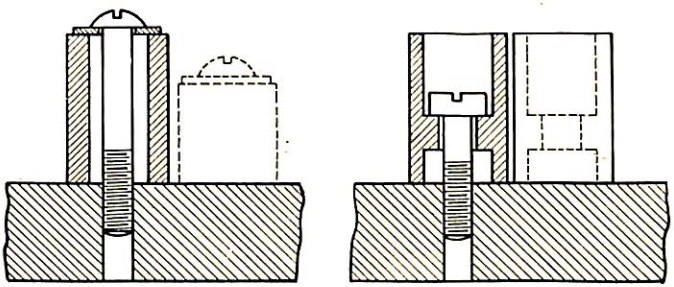


Fig. 1. Types of Toolmaker's Buttons

is required at this stage. Next, using the punch marks as a guide, small holes are drilled and tapped for the reception of the screws whereby the buttons are to be secured to the work. The buttons are then mounted in position, being located approximately from the guide circles provided, and the screws are tightened sufficiently to hold the buttons firmly in place, while at the same time permitting of their subsequent fine adjustment by light tapping. The clearance between the fixed screw and the bore of the button provides ample space for adjustment of the latter. The method adopted for the final setting of the buttons will depend to some extent on the form of this work. In all cases, however, the object is to ensure that the axes of the buttons coincide as nearly as possible with the required hole centres. Suppose, for example that it is required to position three holes *A*, *B* and *C* near the corner of a plate the two adjacent sides of which have been finish ground accurately at

right angles as seen in the view at (*a*) in Fig 2. Here the centre lines and guide circles have been marked out. A plan view of the plate with the buttons attached is shown at (*b*). Suppose now that the work is placed with the edge *X* resting on a surface plate as at (*c*). A height gauge may then be used to check the settings of the buttons in relation to this edge. When the buttons are set correctly the reading of the gauge should correspond to the required

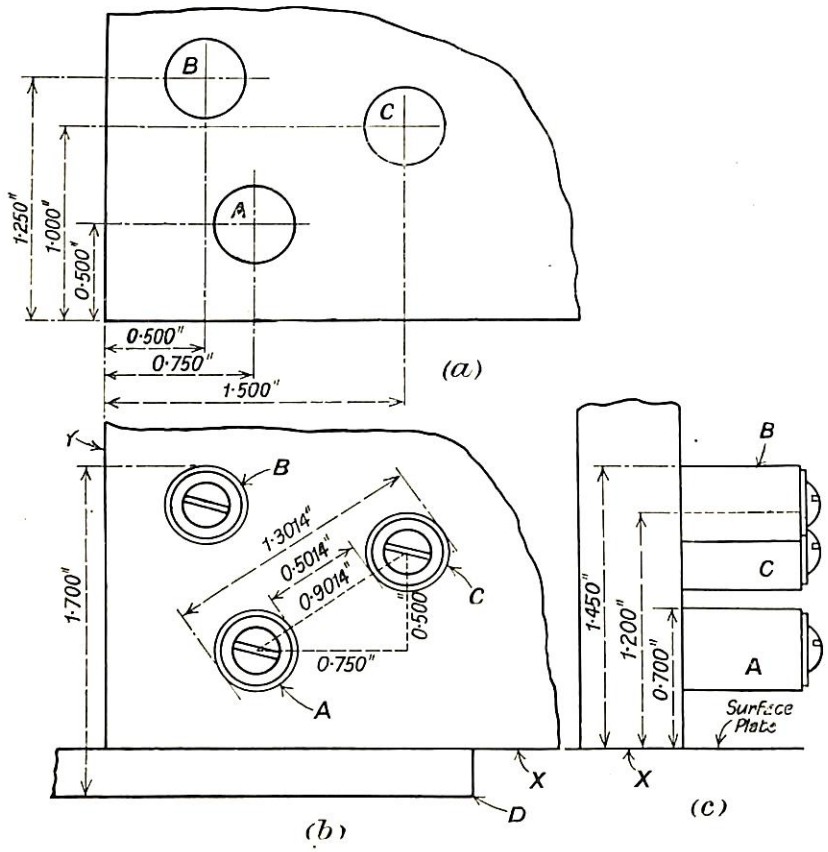


Fig. 2. Method of Locating the Buttons on the Work

centre height of the hole plus half the diameter of the button, assumed in this case to be 0·4-inch. Thus the reading for *A* should be 0·5+0·2=0·7-inch, for *B* 1·25+0·2=1·45, and for *C*, 1·0+0·2= 1·2 inches. Alternatively, provided that the buttons were so positioned that interference did not occur, measurements might be

taken with slip gauges between the surface plate and the underside of each button. In this case, of course, half the button diameter must be deducted from the centre height to obtain the required dimension. Another method of obtaining the settings involves the use of a parallel, say 0·25-inch thick which is clamped against the edge X, as indicated at D, and projects above the surface of the plate. Measurements may then be taken with a micrometer or vernier calipers over the buttons and the parallel. In the case of the button B, for example, the correct reading would be $1{\cdot}25+0{\cdot}2+0{\cdot}25=1{\cdot}7$ inches.

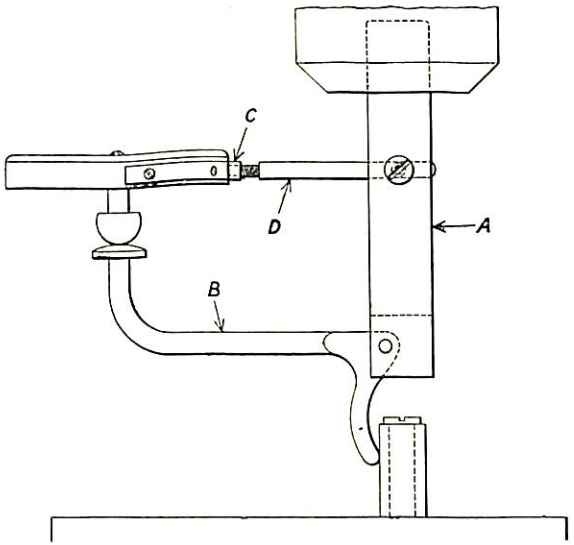


Fig. 3. Method of Mounting Dial Indicator on Milling Machine Spindle for Setting-up Work from Buttons

After the buttons have been positioned in respect to the edge X they can be set in precisely the same way in relation to the edge Y. There is, however, always a risk, if any appreciable adjustment is required at this second setting, that small errors in the distances of the button centres from the edge X may be introduced. It is advisable, therefore, that the measurements should again be checked in relation to this edge to ensure that no displacement has occurred. Obviously considerable time may be required to ensure that all the buttons are correctly position. The method offers the advantage, however, that there is unlimited opportunity for adjustment. When holes are drilled as described in the previous chapter, and afterwards corrected, there is always a risk that too much metal

may be removed. On the other hand, if a button is moved too far in one direction it can always be moved back again.

As a final check, readings may be taken over each pair of buttons, using a micrometer or vernier calipers, or between the buttons, using slip gauges. If the required centre distances between the buttons are not known, they can readily be calculated. In the right angle triangle shown dotted in the view at (*b*) two of the sides are obtained directly from the dimensions given. The length of the third side which is the centre distance between the buttons is given by $\sqrt{0{\cdot}75^2+0{\cdot}5^2}=0{\cdot}9014$-inch. Thus the required measurement over the buttons *A* and *C* is $0{\cdot}9014+0{\cdot}4=1{\cdot}3014$-inch, while the measurement between the buttons is $0{\cdot}9014-0{\cdot}4=0{\cdot}5014$-inch. In a similar manner the centre distances of *AB*, and *BC* may be obtained.

Setting the Work on the Machine

With the buttons accurately located and securely clamped in position the work is transferred to the machine on which the holes are to be bored. Generally speaking it is preferable to perform this operation on a lathe unless the part is of such a size or shape that

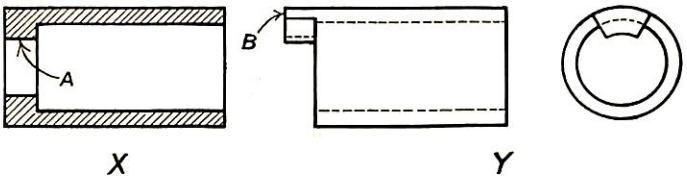


Fig. 4. Bushes for Locating Buttons in Relation to Milling Machine Spindle

this is impracticable. The work is mounted on a faceplate, or an angle-plate attached thereto, and is adjusted until the axis of one of the buttons coincides with the axis of rotation. The setting can best be obtained with the aid of a dial indicator which is mounted in a holder on the tool post. The plunger of the indicator is applied to the surface of the button which the spindle is rotating and any eccentricity is revealed by movement of the pointer. Care must be taken to ensure that the work is in reasonably accurate balance at the spindle speed at which the machining is to be performed. After the setting has been obtained, the button is removed and drilling and boring are performed in the usual manner. As a rule, the tapped hole whereby the button was secured to the work, is slightly eccentric, and it is good practice to chamfer the edge of

this hole with a turning tool in order to provide a true start for the drill.

If boring is to be performed on a milling machine on which the work is stationary, the indicator must be mounted on the rotating spindle. Fig. 3 shows one method of supporting the indicator which offers the advantage that, as the spindle turns, the dial is always visible to the operator standing in one position. The bar *A*, which is held in the spindle and must, of course, run true, is slotted

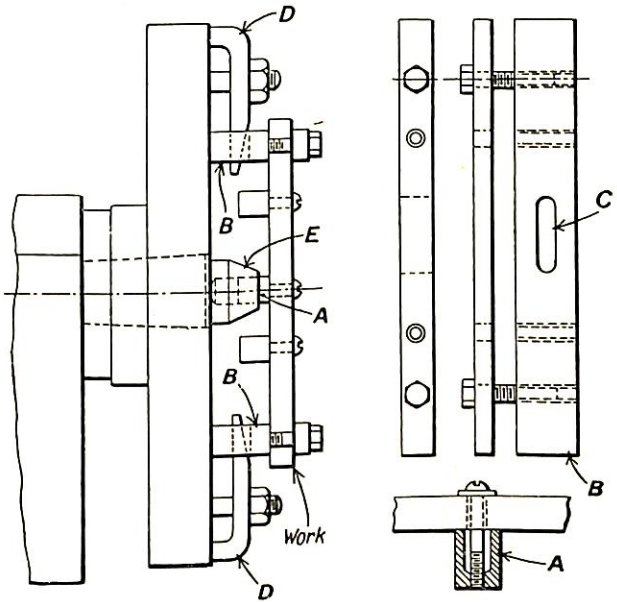


Fig. 5. Modified Form of Button and Method of Locating Work Therefrom

at the lower end to receive the lever arm *B*, the latter being pivoted on a pin, as shown. The arm is flattened where it engages the slot and one end is formed as a contact finger to bear on the button, while the other end is bent and engages the plunger of the indicator which, in this case, projects from the back of the instrument. The strap *C* is bent to suit the outside of the indicator casing to which it is secured by soldering or by screws. A tapped hole in the strap receives the threaded end of the rod *D*, the opposite end of which is inserted in a hole in the bar *A* and secured by a set screw. The degree of accuracy obtainable can be varied to meet requirements by modifying the ratio of the arms of the lever *B*.

An alternative method of locating a button in relation to the spindle of a milling machine involves the use of an accurate bushing as shown at *X* in Fig. 4, one end of which is bored to a close fit on an arbor held in the spindle, while the other end is bored at *A* to suit the diameter of the button. With the bush in position on the arbor, the table is adjusted until the bush can be slid down over the button, thus indicating that the required setting has been obtained. A modified form of bush which offers certain advantages is seen at *Y*. It will be observed that the end is cut away so as to leave a projecting lug *B*, the internal radius of which conforms to the external radius of the button. The bushing is a sliding fit on the arbor and when setting the work the table is adjusted

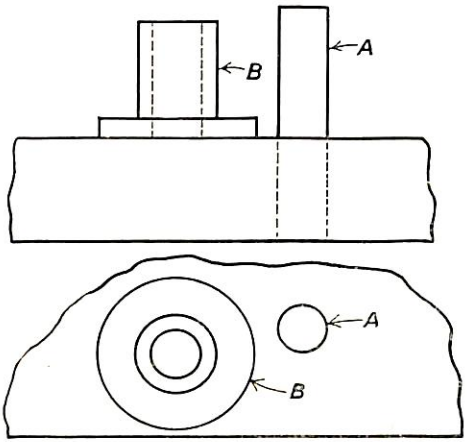


Fig. 6. Flanged Bush through which a Hole may be Drilled and Reamed. The Bush is Located in the same manner as a Button

until the lug clears the button at all points as the bushing is rotated. With this arrangement the operator's view of the button is not obstructed.

At *A* in Fig. 5 is shown a modified form of button which can sometimes be used to advantage where the holes are to be bored on a lathe. In this case a tapped hole is provided in the button for the reception of the securing screw. The threaded portion only extends over about one-quarter of the length of the button, the remainder being counterbored to clear the screw, as shown. A hole is drilled in the work slightly larger than the diameter of the screw to permit of adjustment when setting the button, the screw being inserted from the back or underside of the plate.

Fig. 5 also shows the manner in which the work is located on the faceplate when using buttons of this type. After the buttons have been positioned the work is attached to a pair of special parallels *B*, one of which is shown to an enlarged scale in the upper

right hand view. The opening *C* in the centre of the parallel provides for the reception of the end of the faceplate clamp *D*. In the headstock spindle of the lathe is mounted a master plug *E*, having an accurately bored hole which is concentric with the axis of rotation and is a close fit on the button *A*. With one of the buttons engaging the hole in the plug, the work is secured in position by means of the clamps *D*. The depth of the hole in the plug should be a little greater than the length of the button so that the latter can be pushed into the plug after the work has been clamped and the screw removed. In this way interference with the boring tool is avoided. After each hole has been bored the button can be removed from the plug with a wire hook.

The method illustrated in Fig. 5 is not to be recommended where a very high degree of accuracy is required. Under these conditions the buttons *A* would have to be a push fit in the plug *E* and there would be a risk of slight displacement of the buttons while they were being inserted.

Modifications of the Button Method

Certain modified button methods of hole location are sometimes employed, usually with the object of enabling the work to be completed on a drilling machine rather than on a lathe or milling machine. One such method involves the use of special flanged bushes. These are hardened and ground or lapped in the bores to suit the diameters of the holes to be produced, the outside diameters being afterwards ground concentric with the bores and to convenient dimensions. The flange end face should also be ground flat and accurately at right angles to the axis. The flange should be sufficiently wide to permit of the bush being securely clamped in position on the work. Bushes of this type may be used in the same way as standard buttons, readings being taken over the outside diameters when setting. Then, with the bushes clamped in position, they serve as guides for drilling and reaming the holes. In order to align the bush with the machine spindle when setting up, an accurate plug may be mounted in the latter. When the work is in such a position that this plug will enter the bush it is clamped to the table. The hole may then be drilled about $\frac{1}{64}$-inch undersize after first centring with a full-size drill, and finally brought to the required dimension by reaming. Obviously this method is not applicable to the drilling of holes near the centre of a large plate owing to the difficulty of clamping the bushings. If the holes are located close together, moreover, so that the bush flanges would cause interference, a modified procedure must be adopted.

One hole is first located and machined after which an accurate plug is inserted therein as seen at *A* in Fig. 6. This plug is then

used for taking readings when setting the bush in position for drilling the second hole. While this method will not give results so accurate as are obtainable when using buttons in the ordinary way, it offers certain advantages as compared with the drilling of holes direct from centre punch marks.

Another method, which is illustrated in Fig. 7, while requiring somewhat more elaborate equipment, will enable reasonable accuracy to be obtained regardless of the condition of the plant on which the machining operation is to be performed. A standard button is first located in the usual way, and the two bushes *A* and *B* are then assembled and placed over the button. The inner bush *A* which is provided with a knurled head to facilitate its removal is ground both internally and externally. The bore is finished to

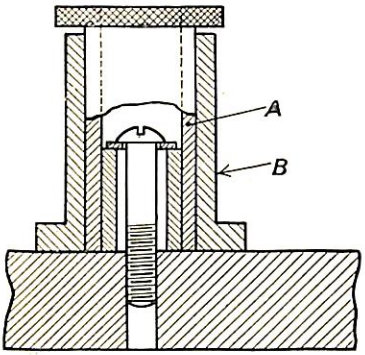


Fig. 7. Method of Locating Pilot Bush from Button

a close sliding fit on the button and the external diameter, which must be accurately concentric with the bore, to a close fit in the outer sleeve *B*. The latter is ground internally and is provided with a flange whereby it may be clamped securely to the work, using ordinary toolmaker's clamps. After the sleeve *B* has been clamped, the sleeve *A* is withdrawn and the button removed. A hole is then drilled and subsequently opened out to the required size using a special cutter bar. The latter is of the floating shank type and is provided with a long pilot portion which is ground to an accurate fit in the bore of the sleeve B. It will be apparent, therefore, that the position and alignment of the hole in the work are entirely dependent on the accuracy and location of the sleeve *B*. The actual cutter may be made integral with the bar or removable, but care must be taken to ensure that it is accurately concentric with the pilot.

A variation of the method described in connection with Fig. 6 is illustrated in Fig. 8. Here the flanged bushes are replaced by tool steel blocks of the approximate form indicated at *A* and about 1-inch thick. The upper and lower faces of these blocks are ground

accurately flat and parallel, and holes of any convenient size, say ½-inch, are drilled and finally lapped after hardening, care being taken to ensure that the hole axes are accurately at right angles to the flat faces. Plugs *B* are ground to a close fit in the holes in the blocks and the latter are then clamped lightly to the work using C-clamps or tool-makers clamps as shown in Fig. 8. The projecting pins serve as buttons from which measurements can be taken, and when the desired settings have been obtained, the blocks are securely clamped. The plugs are then removed, and the holes

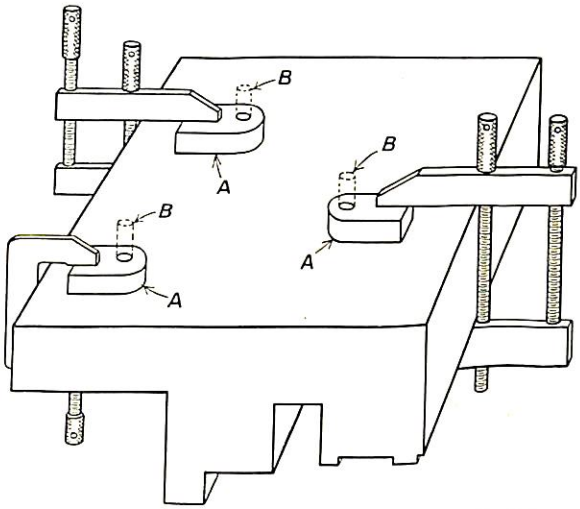


Fig. 8. Use of Steel Blocks with Removable Plugs for Hole Location

drilled and reamed as previously explained. If the required hole is smaller than the hole in the plate *A* a bushing of the appropriate bore size may be inserted. On the other hand, if the hole in the work is to be larger than that in the plate, a ½-inch hole may first be drilled and reamed, and subsequently opened out with a piloted counterbore.

The 3-disc Method of Positioning Holes

As was pointed out earlier in this chapter, the button method of hole location, while yielding very accurate results, occupies considerable time. It is for this reason that the so-called 3-disc method is sometimes favoured. Suppose that it is required to locate three holes, the centres of which are at the corners of a

triangle, as indicated at *A*, *B* and *C* in Fig. 9. It will be obvious that, if three discs of appropriate size were available, they could be placed in position, as shown so that each disc was in contact with the other two, and their centres would then coincide with those of the required holes. The production of a disc of any desired size to close limits of accuracy is, however, a relatively simple matter for the tool-maker, and occupies but little time. It remains then merely to determine the sizes of the discs required in any particular case, and while this method is fairly well known, it is frequently not realized how easy is the calculation involved. The diameter of each disc is equal to the sum of the sides of the triangle which meet at the centre of that disc minus the third side.

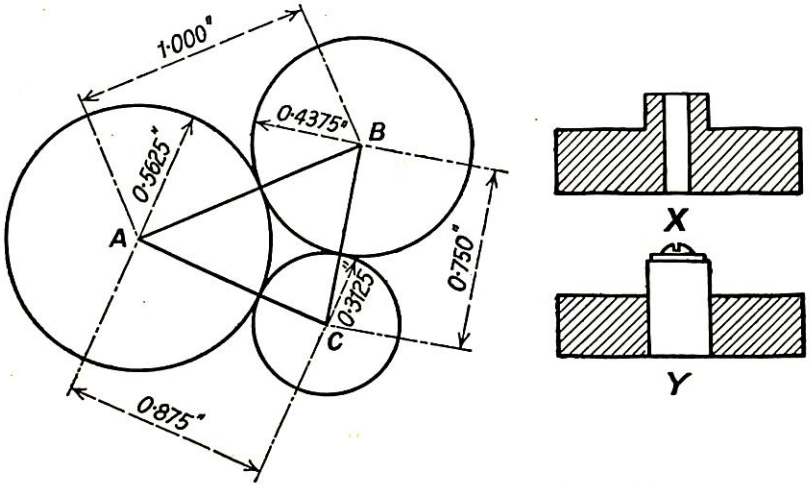


Fig. 9. Diagram Illustrating the 3-disc Method of Hole Location

Thus the diameter of disc $A = 1{\cdot}000 + 0{\cdot}875 - 0{\cdot}750 = 1{\cdot}125$-inches.
Similarly, ,, ,, $B = 1{\cdot}000 + 0{\cdot}750 - 0{\cdot}875 = 0{\cdot}875$-inch.
,, ,, $C = 0{\cdot}875 + 0{\cdot}750 - 1{\cdot}000 = 0{\cdot}625$-inch.

The discs employed for locating holes by this method may either be formed with integral concentric bosses as at *X* in Fig. 9, to which an indicator can be applied when setting up the work on a machine, or they may be bored out to a close fit for standard buttons, as at *Y*. Where an integral boss is provided, a central hole in the disc is necessary for the reception of a screw whereby it may be temporarily clamped to the work.

Suppose that it is required to locate the centres of five holes *A B C D* and *E* on a plate by the 3-disc method, the dimensions being given in rectangular co-ordinates as at *X* in Fig. 10. The

first step is to calculate the sides of the triangle ABC and it is found that AB=2·6926 inches, BC=2·0616 inches and CA=2·2361 inches. The diameters of the necessary discs are then obtained and are as follows: disc A=2·8671 inches; disc B=2·5181 inches; and disc C=1·6051 inches. Since these are all odd sizes it would be necessary to make special discs to the required dimensions.

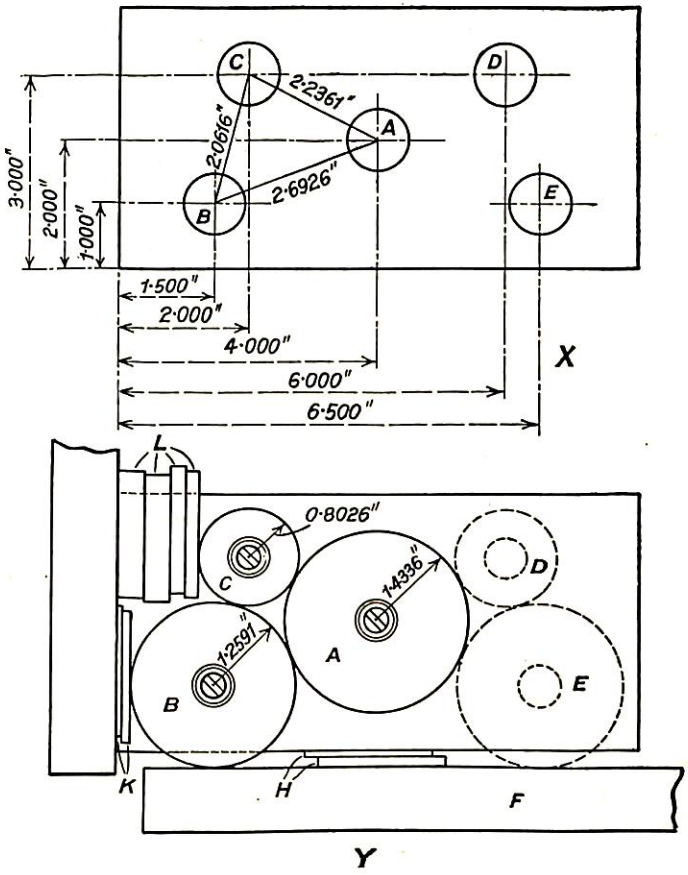


Fig. 10. Procedure Followed in Locating Holes by the 3-disc Method

It will be apparent that the disc B, when in position will overlap one edge of the plate by 0·2591-inch. An accurate parallel or straight-edge F is therefore lightly clamped to this edge with the appropriate slip gauge combination H interposed as seen in the view at Y. A parallel G is clamped to the adjacent edge and since

the distance of the periphery of disc B from this edge should be 0·2409-inch, the necessary slip gauges are placed at K. Now providing that the disc B has been made accurately, when it is held in contact with the parallel F and the slip gauges K its centre will be in the required position.

To facilitate the marking of the hole centres for the button retaining screws, a bush should be provided which is a reasonably good fit in the holes in the discs, and which is bored to receive a centre punch. With the bush and punch in position and the disc B

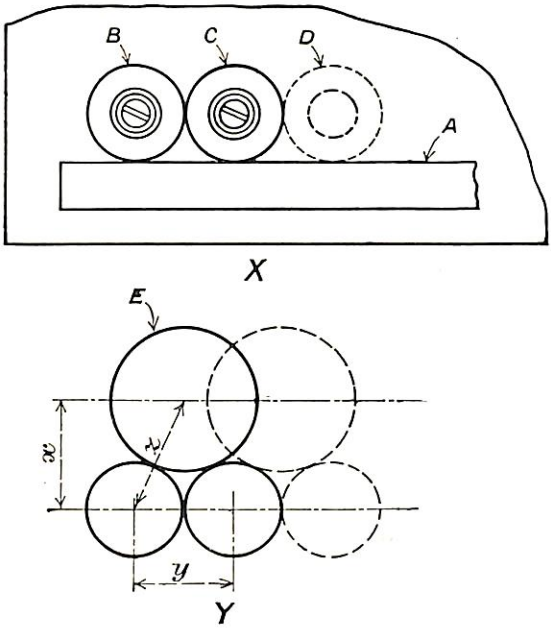


Fig. II. Method of Locating Equidistant Holes in Line Using Accurate Discs

held in contact with the slip gauges and straight edge by hand, the hole centre is marked. The disc B is then removed and the hole is drilled and tapped. Next the disc is again glaced in position with a button in the centre hole and is pressed firmly against the slip gauges and parallel while the button retaining screw is being tightened. The same procedure is followed in connection with the disc C except that this is located by contact with the disc B and the slip gauge combination L. The value of this combination is founding by deducting the radius of the disc C from the 2-inch horizontal dimension in view X, thus 2·0000-0·8026=1·1974-inches.

With the second button secured in position at C, the location of the button at A is obtained when the corresponding disc is in contact with the discs B and C. The disc B may now be removed, leaving the button in position, and transferred to the opposite

end of the plate, the location of the hole E being determined by the contact of the disc with the parallel F and the disc A. Finally the disc C is transferred to the position D, being located by contact with the other two discs. All the discs are then removed leaving the five buttons accurately located in the required positions.

The example illustrated in Fig. 10 has been selected to indicate the procedure followed when locating holes by the disc method rather than as an instance of its practical application. Obviously the method shows to the greatest advantage where the centre distances of the holes are even dimensions so that standard discs can be used. Such discs should preferably be made from tool steel, hardened and ground, although special discs made up to suit a particular job can be left soft. Discs can also be employed to good effect in certain special cases. For example, where it is required to locate a number of equally spaced holes in a straight line it is only necessary to use two discs, of a diameter corresponding to the required centre distance, together with a straight-edge, in the manner shown diagrammatically at X in Fig. 11. The straight-edge A is first located parallel to the required hole centre line and at a distance therefrom equal to half the centre distance of the holes and is clamped in position. One disc B is then placed in contact with the straight-edge and located in relation to the adjacent edge of the work by slip gauges or other means, the hole for the button retaining screw being centre punched, drilled and tapped in the usual way. When the screw has been inserted to secure the button the process is repeated for the disc C, except that in this case location is taken directly from the disc B and the straight-edge. The disc B is then transferred to the position shown dotted at D, and so on until all the buttons have been located. Particularly for a long row of holes the discs must be made very accurately to avoid the introduction of inadmissible accumulative errors.

In a similar manner, parallel rows of staggered holes may be located as indicated in the diagram at Y in Fig. 11. Knowing the spacing y of the holes in the rows and the distance x between the rows, it is a simple matter to obtain the diagonal centre distance z. It will be obvious that the radius of the large disc E must be made equal to $z-\frac{y}{2}$ After the two small discs have been located in the positions shown by the full circles, the large disc E is positioned in contact therewith. The small left-hand disc is then moved to the right to the position shown by the dotted circle, after which the large disc is also moved to the right and again located from the two small discs. The process is repeated step by step until the required number of holes has been located.

It will be understood that where the accuracy requirements are not too exacting, the discs may be arranged to receive bushings through which the holes are drilled and reamed.

CHAPTER 3

LOCATING HOLES ON A CIRCLE

The various methods of location described thus far are, with minor modifications, applicable to the special case, frequently encountered in practice, where the centres of the holes are required to lie on a common pitch circle. The marking out of the centres, or the positioning of the buttons or discs is, however, facilitated in this instance, particularly if the holes are to be equally spaced about the circle. Obviously the accurate spacing of holes on a circle can most conveniently be undertaken with the aid of a dividing head or circular table which permits of the angular indexing of the work to the necessary degree of precision. With such equipment available it is only necessary to locate the work so that the centre of the hole pitch circle coincides with the axis of rotation of the indexing member, and to set the machine spindle so that its axis is displaced therefrom by an amount corresponding to the radius of the pitch circle. The work is then indexed as required for drilling and boring the various holes.

In the absence of such facilities, the procedure to be outlined in this chapter may be successfully employed. If the holes are to be machined direct from centre punch marks in the manner described in Chapter 1, the first step is to set the dividers or trammels as accurately as possible to the required radius and scribe the pitch circle. Alternatively, if a protractor angle plate or similar equipment is available, the work may be rotated while the scribing point of the height or surface gauge is held stationary in contact therewith at the required distance from the axis of rotation. Unless the holes are required to bear a definite relationship to some other feature of the work, such as a notch or lug, any point on the circumference of the circle may be chosen as the centre of the first hole. A light centre punch mark is made at the point selected. Next, with the dividers appropriately set and one point resting in the centre punch mark, an arc is struck to intersect the circle. With the point of intersection as centre, another arc is then struck, the process being repeated until all the hole centres have been obtained. It will be obvious that, whether the holes are equally or irregularly spaced about the circumference of the circle, after the last centre has been located an arc struck therefrom with the dividers suitably set, should intersect the pitch circle at the centre punch mark from

which operations commenced. In this way a check on the accuracy of the work is obtained.

To permit of marking out the hole centres in the manner described, it is necessary to know the various chordal distances such as AB and BC in the diagram at X, Fig. 1. If these dimensions are given on the drawing it is possible to proceed with the work directly. If, on the other hand, the information is limited to the pitch circle radius r and the angles ADB and BDC subtended at the centre, then AB and BC must be calculated, Tables giving chords of circles for various centre angles are given in *Machinery's Handbook*. In order to obtain accuracy to the necessary number

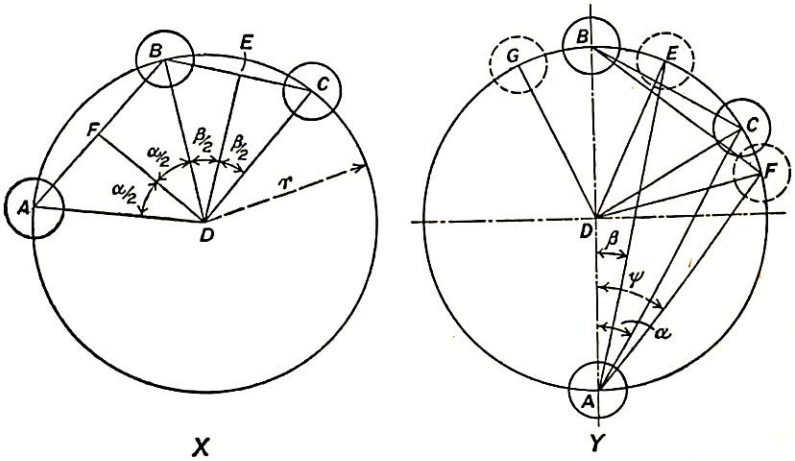


Fig. 1. Diagrams Illustrating the Calculations for the Chordal Distances of Holes on a Circle

of decimal places for tool-making purposes, however, it is usually preferable to perform the simple calculation. Let the angle $ADB=\alpha$ and let the angle $BDC=\beta$, and suppose that the lines DF and DE are drawn at right angles to AB and BC and therefore bisecting the two angles.

Then $AB=2\times AF=2\times AD \text{ Sin } \frac{\alpha}{2}=2r \sin \frac{\alpha}{2}$

Similarly $BC=2r \sin \frac{\beta}{2}$

In the special case where the holes are to be equally spaced around the pitch circle, it is only necessary to know the required number of holes and the centre angle can then be directly obtained by dividing the number into 360 deg. For example, if there are to be eleven holes the centre angle would be $\frac{360}{11}=32$ deg. 43 min.

38 sec. A table in *Machinery's Handbook* gives lengths of chords to six places of decimals for numbers of holes from 3 to 194 on a 1-inch diameter circle. For other circle diameters it is only necessary to multiply these values by the particular diameter required.

Where holes are equally spaced, it is sometimes desirable for checking purposes to know the lengths of the longest and second longest chords in addition to the chordal length between adjacent holes. If the number of holes is even, then pairs of holes such as A and B in the view at Y, Fig. 1, are diametrically opposite so that the longest chord corresponds to the pitch circle diameter. The

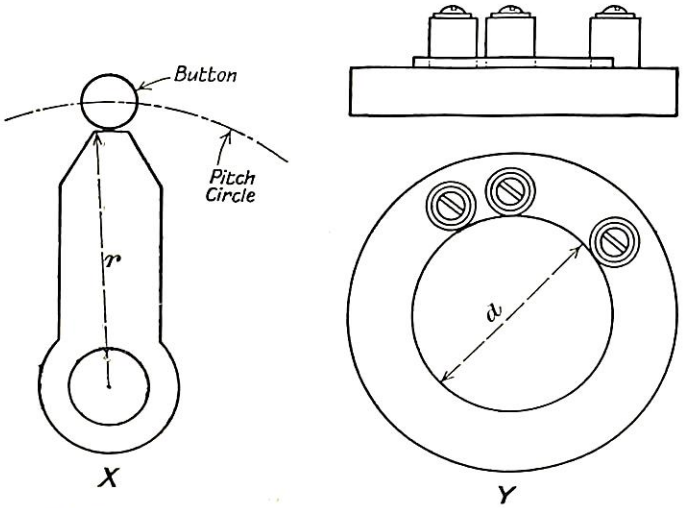


Fig. 2. Diagrams Showing Use of Radius Gauge and Spigot for Setting Buttons on a Circle.

second longest chord is AC. In the triangle ABC $\angle ACB$ is a right angle (angle in a semi-circle).

$\therefore$ $AC = AB \cos \alpha$ = pitch circle diameter $\times \cos \alpha$.

But angle $\alpha = \frac{\angle CDB}{2}$; and angle $CDB = \frac{360}{N}$, where N is the number of holes.

$\therefore$ AC = pitch circle diameter $\times \cos \frac{180}{N}$

If the number of holes is odd, as indicated by the dotted circles E, F and G, then the longest chord is AE. From the triangle AEB:

$AE = AB \cos \beta$ = pitch circle diameter $\times \cos \beta$.

But angle $\beta = \frac{\angle EDB}{2}$; and angle $EDB = \frac{\angle EDG}{2}$; and

$\angle EDG = \frac{360}{N}$ where N is the number of holes.

$$\therefore \beta = \frac{360}{4N} = \frac{90}{N}$$

and AE = pitch circle diameter $\times \cos \frac{90}{N}$

The second longest chord, where the number of holes is odd, is AF. Now $AF = AB \cos \psi$ = pitch circle diameter $\times \cos \psi$.

But angle $\psi = \frac{\angle FDB}{2} = \frac{\angle FDE + \angle EDB}{2} = \frac{1}{2}\left(\frac{360}{N} + \frac{360}{2N}\right) = \frac{270}{N}$

$$\therefore AF = \text{pitch circle diameter} \times \cos \frac{270}{N}$$

Machinery's chart "Chordal Dimensions for Toolmakers" gives the longest and second longest chords for numbers of holes from 3 to 50. Where equally spaced holes are to be marked out, once the dividers have been set to the required chord, the various centres are stepped off around the circle. If the setting is incorrect an accumulative error will be introduced, and when the final check is made, as previously described such an error will be clearly apparent, and the necessary correction can be effected.

Locating Holes on Circle with Buttons

When holes are to be located on a circle using toolmakers' buttons and a central hole is permissible, it is convenient to bore such a hole for the reception of an accurate plug of any suitable diameter. When in position the plug is arranged to project from the surface of the plate, and measurements are taken over the plug and each of the buttons in turn to ensure that the latter are all set at the correct radius. Measurements are, of course, also taken over the buttons to obtain the required angular spacings, the chordal dimensions having previously been determined.

If a large number of holes is to be located, as for example, when producing a special index plate, time may sometimes be saved and greater accuracy ensured by using a radius gauge of the form shown at X in Fig. 2 for setting the buttons. This gauge is ground accurately flat on one side, and the hole is ground and lapped to a close fit on the projecting central plug. The dimension r is made equal to the required pitch circle radius minus the radius of the buttons to be used.

As an alternative, the plate in which the holes are to be bored may be machined with a shallow central spigot as seen in the view at X, Fig. 2, the diameter of the spigot d being held within close limits to the dimension obtained by deducting the button diameter from that of the pitch circle. When positioning the buttons they are held in engagement with the spigot, the angular spacing being obtained by measuring over the buttons in the usual way.

The setting of buttons for locating holes on a circle may be further facilitated if a shallow annular groove is machined in the

plate. The diameter of the groove centre should correspond to that of the required pitch circle and the width of the groove should be made equal to the diameter of the buttons within close limits. An example of a jig plate which was produced in this way is seen in Fig. 3, and it will be observed that the buttons are positively held at the correct radius so that manipulation to obtain the required angular settings is simplified. The central register whereby this particular jig plate is located in relation to the work, was machined at the same setting as the groove, concentricity being thereby ensured. The surplus metal at the sides of the groove is machined away after the holes have been bored, and the same applies to the central spigot in the view at *Y*, Fig. 2.

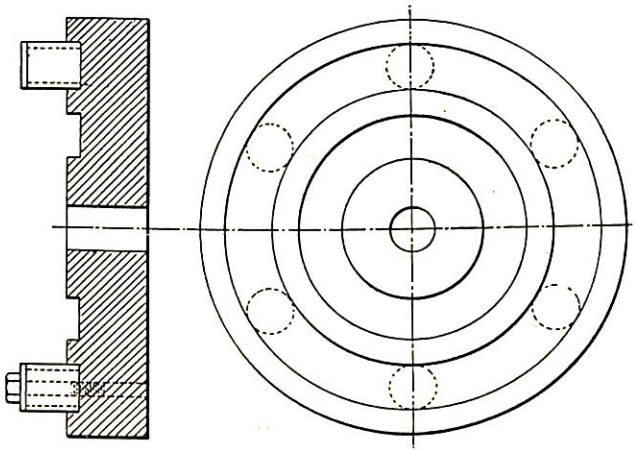


Fig. 3. By Providing a Shallow Annular Groove in the Work the Buttons are Positively Located at the Required Radius

Where a considerable number of equally spaced holes must be located on a circle and the accuracy requirements are not too exacting, considerable time can be saved by adopting the following method. A hole is first bored at the centre of the plate and two adjacent buttons are then positioned as accurately as possible on the circumference of the required pitch circle. The work is next mounted on a backing plate in which a plug has been inserted, this plug being a close fit for the previously bored centre hole. The two plates are then secured to the face-plate of a lathe as shown in Fig. 4, being adjusted until one of the buttons is co-axial with the spindle. In this position, a hole of the required size is drilled and bored through both plates. After inserting an accurate plug in this hole, the plates are again adjusted until the second button

is accurately aligned, and a second hole is drilled and bored. Thenceforth the setting of the backing plate is not disturbed. To locate the work for machining the third and subsequent holes, it is only necessary to release the clamps securing it to the backing plate and turn it until, for example, the second hole is aligned with the hole in the backing plate. The setting is determined by inserting the plug in the two holes in question, and the process is repeated until all the holes have been completed. With this method there is no provision for correcting the accumulative error, and special care is therefore necessary in the initial setting of the two buttons.

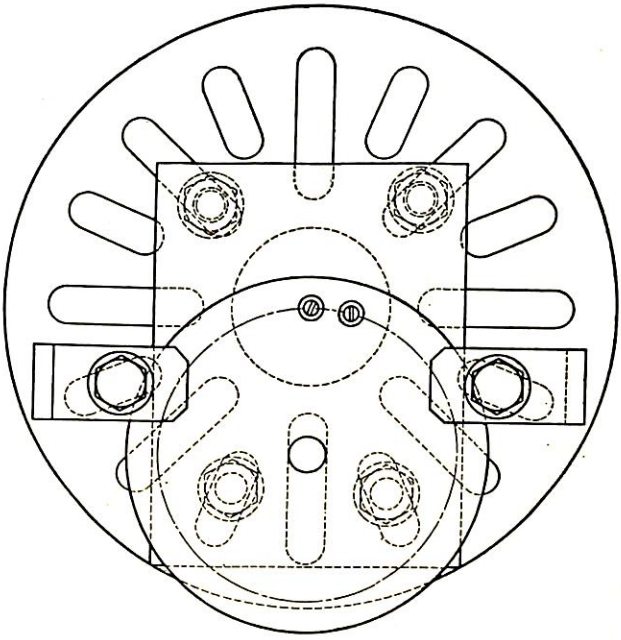


Fig. 4. A Rapid Method of Positioning Equally Spaced Holes for Boring on a Lathe

The disc method lends itself particularly well to the location of equally spaced holes on a circle. The diameter of the discs should normally be made equal to the chordal spacing of the holes required, although where the number of holes is small and the diameter of the discs might be inconveniently large, it may be preferable to employ twice as many discs as there are holes to be machined. For example, if the number of holes is five, ten discs may be used, the diameters of which are found by calculating the chordal spacing for ten holes on the required pitch circle. In this case, alternate

discs are used to locate buttons or to receive drill bushes, the intermediate discs being left plain.

The discs may be positioned round the circumference of the circle with the aid of a large central disc, or by means of a central spigot as at *X* in Fig. 2, or an annular groove machined in the plate as in Fig. 3. The required diameter of the central disc or spigot is obtained by deducting the calculated diameter of the smaller discs from the required pitch circle diameter. Two small discs can be used, these being advanced step-by-step in a manner similar to that described in Chapter 2. For very accurate work, however, it is preferable to provide enough small discs to form a complete ring round the central disc or spigot, as seen in Fig. 5. In this way a check on accuracy is automatically provided. If there

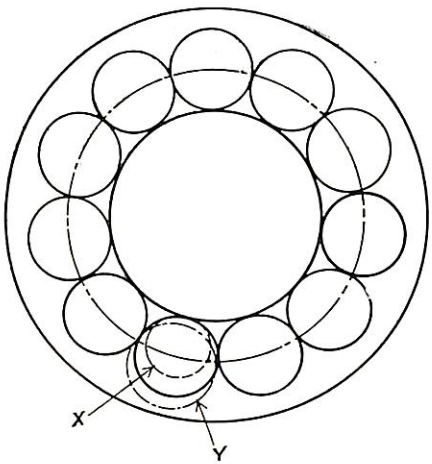


Fig. 5. By using a Complete Ring of Discs, Accuracy is Automatically Checked before Machining Commences

is any appreciable error, either the last disc will not fill the gap remaining, or it will be impossible to insert it in the gap. These two conditions are illustrated diagrammatically by the dotted circle *X* and the chain dotted circle *Y*, respectively. Steps can then be taken to eliminate the error before the machining of the holes commences. The discs must, of course, be of uniform diameter within close limits, and the possibility of errors cancelling out due to the diameters of the central spigot and the discs being both oversize or both undersize, must not be overlooked.

The Split Ring Method of Obtaining Accurately Spaced Holes on a Circle

Holes can be positioned on a circle to a high degree of accuracy as regards their angular spacing by the so-called split ring method. This method is only applicable where the holes are required to be

evenly spaced, and, since it is not possible to hold the pitch circle diameter to close limits, its usefulness is limited for the most part to such work as the boring of holes in index plates. Referring to the view at *X* in Fig. 6, the disc or ring in which the holes are to be bored is made in two sections at *A* and *B*. These must be an accurate fit in relation to one another. The centres of the required holes are first laid out as accurately as possible on the ring *A*. The parts *A* and *B* are then clamped together and the holes are drilled through both. Obviously, when the holes are laid out and drilled in this way, there will be some errors in spacing, and consequently, all the holes will not match except when the ring *A* is in the position which it occupied while being drilled. Whatever errors may exist in the spacing, however, can be eliminated by successively turning the ring *A* to different positions and re-reaming

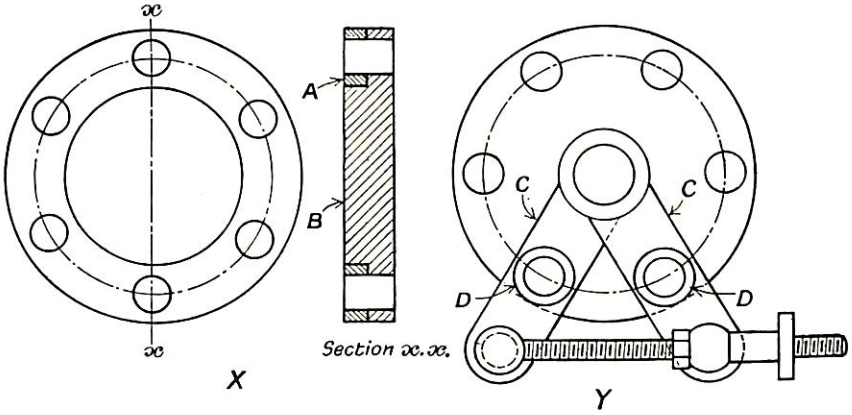


Fig. 6. Diagrams Illustrating two Methods of Accurately Dividing a Circle

the holes at each setting. A taper reamer should be used for this work, and two pins should be provided having the same taper as the reamer. The ring *A* is first located so that a hole is accurately aligned with one in the lower plate. The ring is then clamped and the hole is partly reamed, the reamer being introduced sufficiently far to machine the hole in the ring *A* for its full depth and to take a cut all round the upper portion of the hole in the plate *B*. One of the taper pins is then driven into this hole, and a hole on the opposite side is partly reamed for the reception of the second pin. The remaining holes are next reamed in the same way, the reamer being fed in to the same depth in each case. If a pair of holes is considerably out of alignment, it may be necessary to insert the reamer to a greater depth than was required for the first pair, and in this case all the holes should be re-reamed to secure a uniform size.

After removing the taper pins and clamps, the ring *A* is then turned through an angle corresponding to the spacing of the holes and again secured in position. The reaming process just described is now repeated. Holes on opposite sides are reamed somewhat deeper than before, the taper pins are inserted, and the remaining holes are reamed out to the same depth, so that all are in accurate alignment with the ring in the new position. By repeating this process of turning the ring *A* and re-reaming the holes, any errors in the original spacing of the holes are practically eliminated. It will be understood, however, that it is almost impossible by this method to ensure that the centres of the finished holes will lie on any particular pitch circle within close limits.

Spacing Holes Accurately by Progressive Correction of Accumulated Error

Another method of positioning a number of evenly spaced holes about the circumference of a circle within close limits involves the use of the simple equipment shown somewhat diagrammatically at *Y* in Fig. 6. An accurate plug is inserted in a central hole in the plate, and the two arms *c* are bored to a close fit on this plug, about which they can be turned as required. A fine-pitch screw and nut at the outer ends of the arms provides for adjusting the included angle, the setting being retained by a lock-nut. The arms are bored to receive accurate hardened-steel bushes *D*, the centres of which are located at the required radial distance from the axis of the central plug. The bushes are used as a guide for the drill and reamer when machining the holes in the work. In order to permit of locating holes on different pitch circles, the bushes may be inserted in blocks which can be adjusted along slots in the arms.

After calculating the chordal distance corresponding to the required spacing of the holes the arms are adjusted until the centres of the bushings are at the correct distance. Setting is facilitated by inserting accurate plugs in the bushings over which measurements may be taken with a micrometer or vernier caliper. A hole is next drilled and reamed through one of the bushes somewhat smaller than the required finished diameter. A plug is then inserted through the bush and hole, thereby locating the device while the adjacent hole is drilled and reamed through the bush in the other arm. The plug is now removed and the arms are turned until the bush through which the first hole was drilled is in line with the second hole. The plug is then again inserted and the third hole drilled and reamed, the process being repeated until the required number of holes has been obtained. It will almost invariably be found that there is an appreciable error in the distance between the first and the last hole machined, because any inaccuracy in the initial setting of the arms will have been multiplied by the number of holes. The error should be determined as accurately as possible and the setting of

the arms adjusted accordingly. Bushes slightly large in diameter than those previously employed are then inserted in the arms and the holes are again reamed. This operation is repeated, if necessary, until there is no measurable error in the distance between the first and last holes, after which the holes are opened out to the specified diameter.

Modified Adjustable Parallels for use when Drilling Small Holes

When holes are to be machined on a circle which are too closely spaced to permit of the normal button method of locating and boring being employed, an adjustable parallel may sometimes

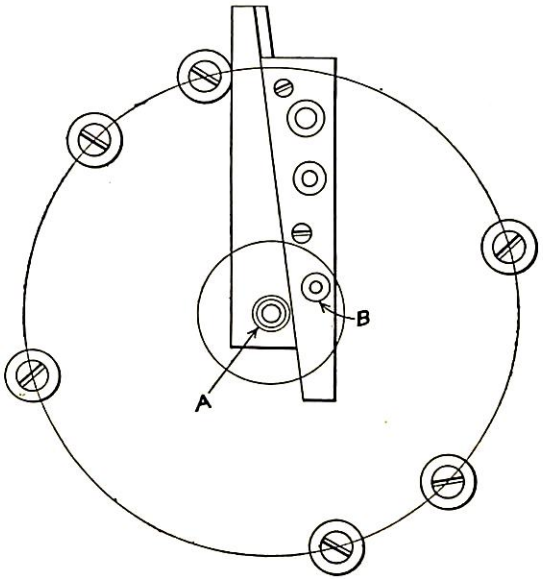


Fig. 7. Modified Taper Parallel used in conjunction with Buttons for Drilling Holes in Small Parts

be used to advantage. A hole is machined in one half of the parallel near one end to receive a bushing of convenient size, for example, $\frac{1}{4}$ inch in diameter, as indicated at *A* in Fig. 7. In the opposite half two or three holes are provided for the reception of bushings, the bores of which correspond to the diameters of the holes to be drilled. No particular care is necessary in locating the holes for the bushings but they should be accurately at right angles to the flat surfaces of the parallel. Provided that the holes are finished smoothly and to correct size, the bushings can be inserted in the

split half of the parallel with sufficient pressure to hold them firmly in position and yet not interfere with the sliding action. The bushings may be made from drill rod, hardened, and lapped to size after insertion.

In order to obtain a setting so that the centre of the hole in the bush *B*, for example, is at a given distance from the hole in the centre of the bush *A*, small accurately fitting plugs are inserted in the holes over which a reading is taken with the aid of a micrometer or vernier calliper. With the plugs at the required distance apart, the two halves of the parallel are locked thus obtaining a solid jig. A second clamping screw may be provided to prevent the possibility of slipping after the setting has been obtained. If the bushings are arranged to fit flush on both sides, the usefulness of the parallel for its normal work is unimpaired.

When using an adjustable jig of this type, a flat plate is provided with a locating pin or button, and buttons are arranged around the periphery of a circle of convenient radius to suit the requirements of the work. Assuming that the part in which the holes are to be drilled is a disc with a central bore that has already been machined, it is placed over the locating pin. The latter should, of course, be a good fit in the bore. Next an adapter bush is placed over the projecting end of the pin, the outer diameter of this bush being a good fit in the bore of the bushing *A*.

With the parallel set and mounted in position, as shown in the figure, in contact with one of the buttons, the first hole is drilled through into the supporting plate. A pin inserted in this hole prevents accidental movement of the blank while the remaining operations are performed. The parallel is brought into contact with each of the buttons in turn and clamped in position while successive holes are drilled. If the holes are to be drilled in a plate of rectangular or other shape, care must be taken to insure that the work is set in the correct angular relationship with the buttons prior to drilling the first hole.

CHAPTER 4

MISCELLANEOUS METHODS OF HOLE LOCATION

Apart from the methods described in the earlier chapters of this book there are various other ways in which holes can be located to reasonably close limits of accuracy with a minimum of special equipment, and some of these will now be considered. In Fig. 1 is shown a method of locating work for boring on a lathe face-plate with the aid of accurate parallels and slip gauges. The parallels are attached to the face-plate at right angles to each other and are so located that when the work is in contact therewith the centre of one of the holes to be bored will coincide with the lathe spindle

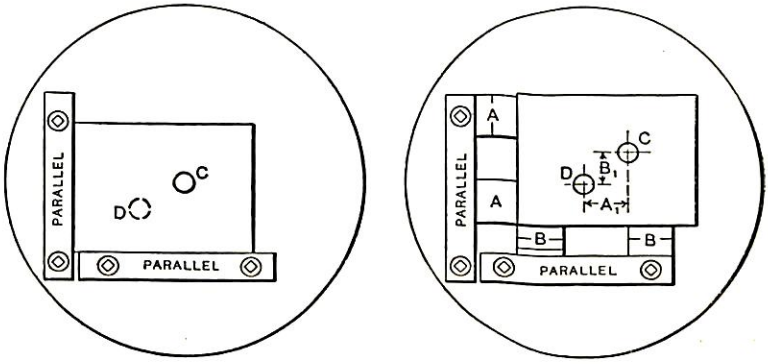


Fig. 1. Method of Setting Work on a Face-plate with the Aid of Parallels and Slip Gauges

axis, it being assumed, of course, that the work has previously been accurately squared up on two sides. The hole which is aligned in this way should be the one which is nearest to the outer corner, for example C, so that the remaining holes can be brought successively into the central position by adjusting the work away from the parallels. After the first hole has been bored, the work is located for boring each subsequent hole by placing the appropriate slip gauge combinations between the edges of the work and the parallels. For example, to set the work for boring the hole D, gauge combinations equal to the dimension A_1 would be inserted at A, and other combinations equal to the dimension B_1 at B. The same method can, of course, be used for setting work on the table of a milling or drilling machine.

The Compound Slide Dividing Table

The compound slide dividing table represents a refinement of the method of location just described. This comprises a base carrying a compound slide, the two moving members being guided so that they move in directions accurately at right angles. For traversing the lower slide on the base, and the upper slide on the

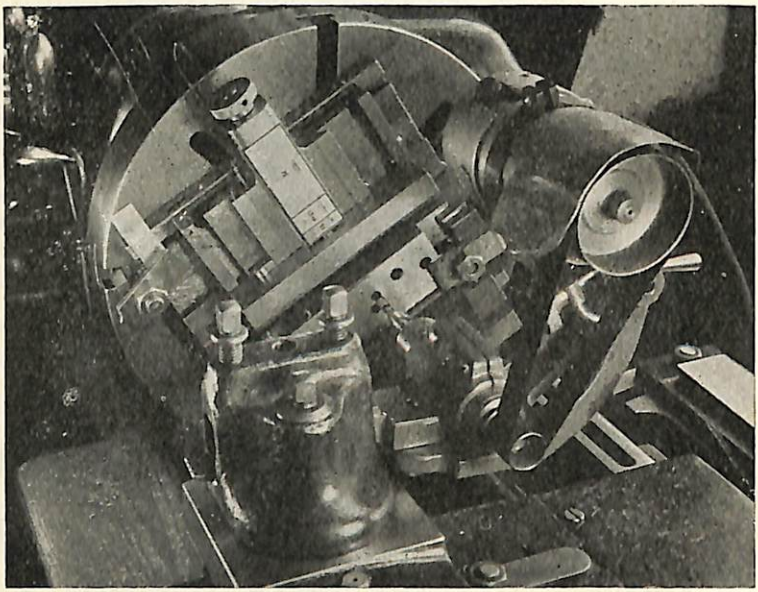


Fig. 2. Use of Compound Slide Dividing Table for Finish Grinding Accurately Spaced Holes on a Lathe. (*Photo by C. E. Johansson, Ltd.*)

lower slide, screws are provided, but the actual settings of the slides are determined by slip gauge combinations inserted between hardened locating surfaces on the fixed and moving members. Thus one combination is placed between a locating surface on the base and one on the lower slide, and the second combination between surfaces on the upper and lower slides. Provision is made for clamping the slides securely in position when the required setting has been obtained, and the upper slide is formed with T-slots to facilitate the mounting of the work.

The dividing table may be secured to the table of a milling or drilling machine, or to the face-plate of a lathe, as seen in Fig. 2. When one of a group of holes in a work-piece has been centred by manipulation of the slides, it is then a simple matter to bring the centres of the remaining holes successively into alignment with the spindle. The holes may thus be bored or, as in the example illustrated, finished after hardening with the aid of a tool-post

grinder. The slip gauge combination for positioning the upper slide in relation to the lower slide may be clearly seen.

If the work takes the form of an irregular casting for a jig or machine in which holes are to be bored, a similar procedure to that described in connection with Fig. 1 may be employed, but in this case the part must first be secured to an auxiliary plate having accurately finished square edges. Such a plate is seen at *A* in Fig. 3

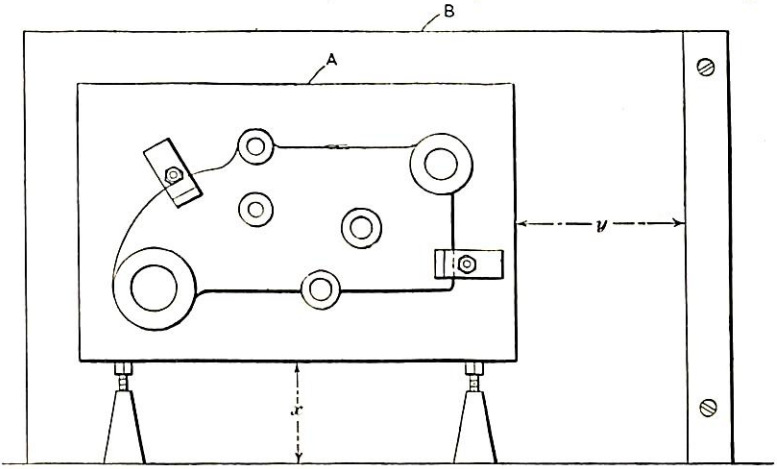


Fig. 3. Method of Locating a Part of Irregular Shape for Boring Holes

where it is being used in conjunction with an accurate angle plate *B*. The work is secured to the plate *A* and the setting is not disturbed until the boring operations have been completed. The angle plate is set so that the plane of the face is at right angles to the machine spindle axis and a parallel strip is bolted to one edge from which horizontal measurements may be taken. This strip must be located so that the edges are at right angles to the surface of the machine table. With the plate *A* clamped to the angle plate so that adjacent edges are in contact with the machine table and the edge of the parallel strip one of the holes is bored. Subsequent settings are then obtained by taking measurements at x and y. Slip gauges may be employed for this purpose although, if the distances are large, it may be more convenient to employ an internal micrometer. To facilitate setting, the plate *A* may, with advantage, be supported on jack screws, as shown.

Another method of setting work in relation to an accurate angle plate in order to permit of boring a series of holes is illustrated in Fig. 4. Here again the angle plate is set so that the plane of the face is at right angles to the machine spindle, and after the first hole has been bored the work is adjusted with the aid of depth micrometers, applied as shown, and supplemented, if necessary, by size blocks. The micrometers may, with advantage, be clamped to the

angle plate and it is of course essential that both the plate and the work should have two adjacent surfaces finished accurately flat and mutually at right angles, from which measurements can be taken.

Adjustable Jigs for Drilling and Reaming Accurately Spaced Holes

In Fig. 5 is shown an adjustable jig whereby holes may be drilled and reamed in accurate relationship. It is particularly suitable for use where the holes are required to be equally spaced in a straight line. The two end holes should preferably have been previously located and bored by one or other of the methods already described.

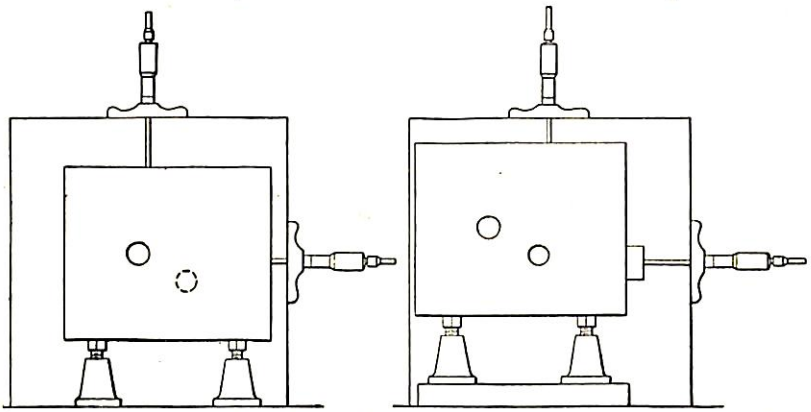


Fig. 4. Locating Work for Boring from the Edges of an Angle Plate with the Aid of Depth Micrometers

The intermediate holes may then be located to a high degree of accuracy with the aid of the jig by making use of the principle of the multiplication of errors. Two guide bushes are accommodated in the slides *A* and *B* which are independently adjustable along the dovetail guide after loosening the screws which secure the clamp-gib *C*. In use, the slides are set so that the distance *x* as measured by micrometer or other convenient means is equal to the required centre distance plus the sum of the radii of the bushings. A straight edge is then clamped to the work in such a position that when the body of the jig is in contact therewith an accurately fitting plug can be inserted through one of the bushings and introduced into either of the previously bored holes. Then, with a plug engaging, say, the bushing *B* and one of the holes in the work, the first of the intermediate holes is drilled and reamed through the bushing *A*. This hole should be left slightly undersize to allow for subsequent correction if necessary. The jig is then moved to the left until a plug can be inserted through the bushing in the slide *B* and the hole just drilled. Since this hole is somewhat undersize, however, either a smaller bushing and plug must be substituted, or a 2-diameter

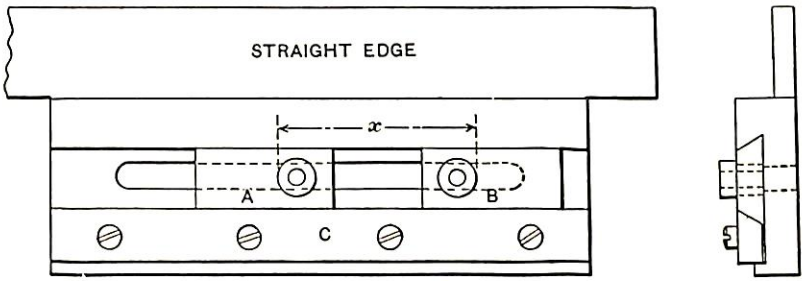


Fig. 5. Adjustable Jig for Accurate Hole Spacing

plug may be employed in conjunction with the original bushing. The process is then repeated until all the intermediate holes have been drilled. If the holes are correctly spaced, when the bushing in the slide *B* is registered with the last hole drilled, the bushing in the slide *A* should be in accurate alignment with the hole originally formed at the left hand end of the row. If, however, there was any appreciable error in the setting of the slides, this error will have been multiplied by the number of intermediate holes, and will thus be clearly apparent when an attempt is made to insert test plugs through the bushings to engage simultaneously with the left hand end hole and the one adjacent thereto. Should an error be detected, the setting of the slides must be adjusted accordingly before the holes are opened out to the required size.

A somewhat similar jig, but capable of more universal application is shown in Fig. 6. Here the drill bushing is accommodated in a block which is slotted to fit the beam *A*. The beam is secured to the stop block *B*, thus forming a miniature T-square. Care must be taken that the block is made to such dimensions and the bushing hole so located as to facilitate measurements when the block is being located in the required position. A knurled head screw is

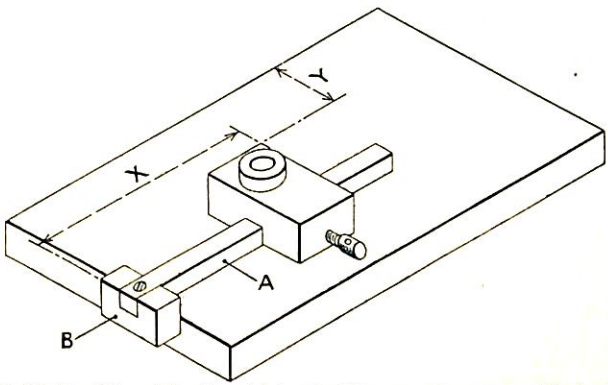


Fig. 6. Drill Bushing Block which Facilitates Accurate Hole Location

provided to permit of locking the block to the beam after the required setting has been obtained. The dimension *X* may be measured from either the outer or the inner surfaces of the drill and stop blocks, while measurement of the dimension *Y* can be conveniently made with a micrometer depth gauge. When the device has been correctly located on the work it may be clamped in position.

An adjustable jig of a rather different type is seen in Fig. 7. It takes the form of a hardened and ground block *A* provided with holes to receive the four sliding pins *B* and the drill bushing *C*. Each pin is secured in position, when set, by means of two headless set screws, small copper or brass slugs being interposed between the ends of the screws and the pins so that there is no risk of accidentally moving the latter when tightening up. A series of bushings may be provided to suit drills of different sizes, and the hole for their reception is so positioned in relation to the edges of the plate as to facilitate estimation of the amounts by which the pins *B* should project in any particular instance. The plate in which the holes are to be located is first accurately finished on two adjacent edges, and parallels are then clamped to these edges so that they overhang as indicated in Fig. 8. The pairs of pins *B* are set with the aid of an external micrometer or a micrometer depth gauge so that they project by the amount required to bring the axis of the bushing *C* into the desired position in relation to the finished sides of the plate. The jig block is then secured to the plate with a pair of parallel clamps, the ends of the pins *B* being in contact with the projecting portions of the parallels. After drilling and reaming one hole the jig block is removed and the pins are re-set before repeating the process.

In Fig. 9 is shown a simple jig for use when series of holes are to be drilled in straight lines, not necessarily equally spaced. It comprises a set of bushings which serve as drill guides, a pair of parallels for clamping the bushings, and knurled clamping screws

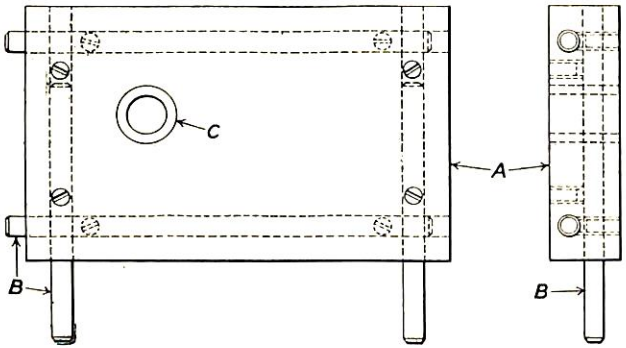


Fig. 7. An Adjustable Drill Jig with Provision for Micrometer Setting

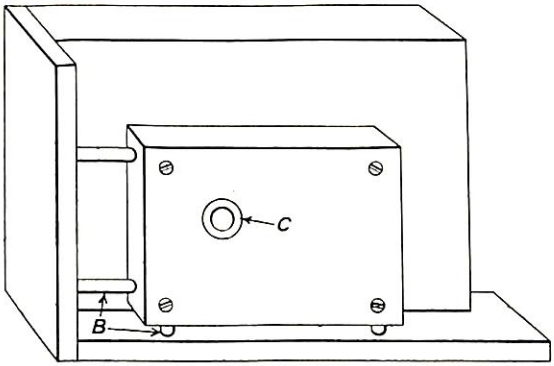


Fig. 8. Diagram showing the Method of Applying the Jig in Fig. 7

and nuts. For setting the bushings, measurements are taken over the heads which are all finished accurately to the same diameter X. When setting, the parallels are tightened up with just sufficient pressure to permit of the bushings being moved by tapping them lightly and they are finally clamped securely. The entire jig is then located and clamped on the work. It will be observed that sufficient clearance is left, as at C, under the heads of the clamping bolts and the clamping nuts to permit of the use of a square or protractor blade to facilitate the setting of the parallels in the required relationship to the previously finished edges of the plate in which the holes are to be bored. Linear measurements may also be taken between the edges of the parallels and those of the work plate.

If the number of holes to be drilled is greater than the number of bushes which can be accommodated between the parallels at one time, the work may be done in stages. After having drilled a

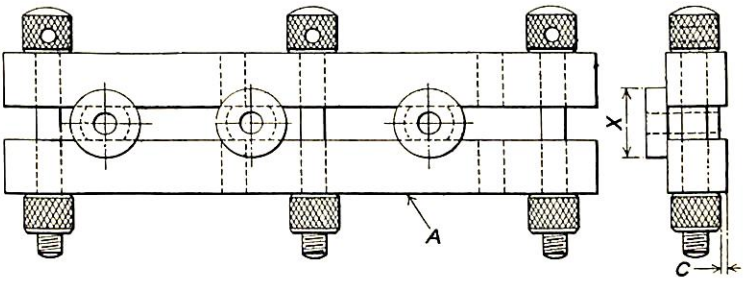


Fig. 9. Another Simple Form of Jig for use when Drilling Holes in a Straight Line

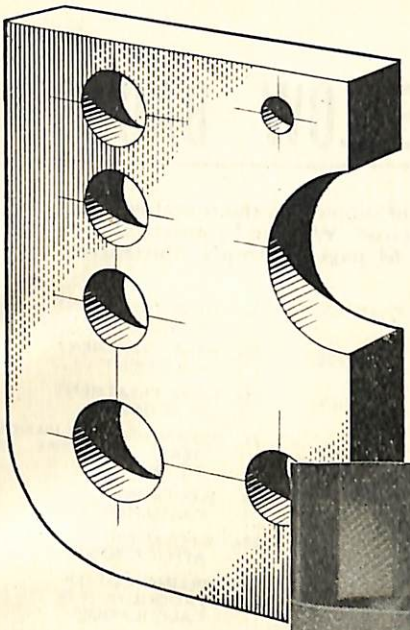
series of holes corresponding to the initial setting of the bushings, a plug is inserted through one bushing and the corresponding hole. With one of the parallels, for example *A*, still clamped securely to the work, the clamping nuts are loosened and the remaining bushings are re-adjusted in relation to the bushing which is positively located by the plug. Since the parallel *A* is not disturbed, it is ensured that all the holes will be in a straight line.

The parallels, which are hardened and accurately ground, are provided with additional holes so that the clamping screws can be moved, if necessary, to avoid interference with the bushings. The latter are formed with flats, as shown, to permit of their being gripped securely. The holes in the work may be drilled and reamed to any convenient size and afterwards opened out if necessary with a piloted counterbore.

INDEX

	PAGE
Accumulated spacing error, progressive correction of	46
Bush, locating pilot, from button	32
Bushes, flanged, for positioning holes	31
Button method, modifications of	31
Buttons, locating on circle with spigots and grooves	41
Buttons, toolmakers'—	
for closely spaced holes	24
locating on circle	41
method of positioning	25
modified, to facilitate work setting	30
positioning relative to lathe spindle axis	28 and 30
,, ,, ,, milling machine spindle	29
setting with height gauge	26
,, ,, micrometer	27
,, ,, slip gauges	27
sizes of	24
Centre points:	
correcting position of	6
initial marking of	5
marking out with aid of locating block	8
Centres, marking, on milling machine	10
Chordal distances, method of calculating	39
Chords, calculating longest and second longest	40
Circle:	
locating equally spaced holes on, with discs	43
,, holes on, by split ring method	44
marking out hole centres on	38
rapid method of boring equally spaced holes on	42
Compound slide dividing table	50
Countersink, correcting preliminary	21
Countersinking punch marks prior to drilling	21
Disc method of locating holes	33
Discs:	
use of, for positioning holes in line	3
,, ,, ,, on a circle	43
Dividing table, compound slide	50
Drilled hole:	
correcting preliminary	22
opening out, to final size	22
Drilling from punch marks at one operation	21
Gauge, radius, for locating buttons on circle	41
Guide circles and squares	11

	PAGE
Indicator for locating punch marks	19
Jig plate, simple, located from punch mark	23
Jig :	
adjustable for accurate hole spacing	52
simple, for locating holes in line	54
universal, method of applying	54
Jigs, universal, for toolmakers	53 and 54
Layout lines, scribing, on milling machine	11
Lathe, advantages of, for producing accurate holes	23
Locating block for centre punch	8
,, irregular shaped part for boring	51
,, work on face-plate with slip gauges	49
Micrometers, depth, locating work for boring with	52
Milling machine, use of, for marking centres	10
Parallels, modified adjustable, for use when drilling small holes	47
Punch :	
centre, for marking scribed line intersections	6
,, locating block for	8
following, for enlarging centre marks	7
holders for use on milling machine	10
Punch marks :	
indicator for checking spacing of	13
micrometer for checking spacing of	15
Radius gauge for locating buttons on circle	41
Slip gauges :	
use of, for locating work on face-plate	49
,, ,, positioning locating block	9
Spacing error, progressive correction of accumulated	46
Split-ring method of locating holes on circle	44
Wiggler for use on milling and drilling machines	18
Wigglers for locating punch marks	16



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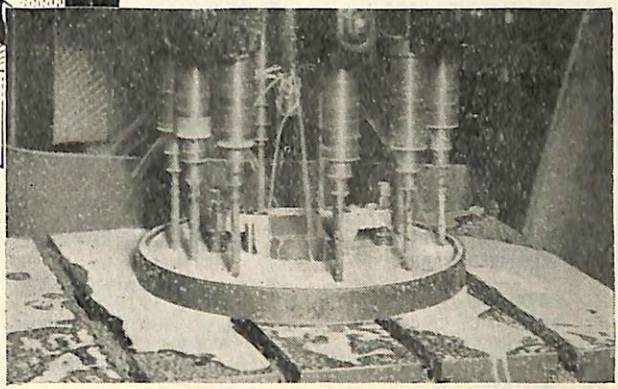

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7. METAL SPINNING.
8. THE SIMPLE CAMS.
9. CENTRELESS GRINDING, PART I.
9a. CENTRELESS GRINDING, PART II.
9b. CENTRELESS GRINDING, PART III.
10. HYDRAULIC OPERATION OF MACHINE TOOLS.
10a. HYDRAULIC PUMPS & MOTORS FOR MACHINE TOOLS.
10b. HYDRAULIC CIRCUITS FOR MACHINE TOOLS.
10c. VALVE GEAR FOR HYDRAULIC MACHINE TOOLS.
12. CENTRE LATHE PRACTICE, PART I.
12a. CENTRE LATHE PRACTICE, PART II.
13. TOOL-ROOM PRACTICE, PART I.
13a. TOOL-ROOM PRACTICE, PART II.
13b. TOOL-ROOM PRACTICE, PART III.
13c. TOOL-ROOM PRACTICE, PART IV.
13d. TOOL-ROOM PRACTICE, PART V.
14. MILLING.
15. BARREL POLISHING.
16. SOLUTION OF TRIANGLES, PART I.
16a. SOLUTION OF TRIANGLES, PART II.
16b. LOGARITHMS OF TRIGONOMETRICAL FUNCTIONS.
17. TROUBLES EXPERIENCED WITH AUTOMATICS.
18. PRESS PRACTICE WITH RUBBER DIES.
19. FINE GRINDING AND LAPPING.
20. NEGATIVE-RAKE MILLING.
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22. JUNIOR DRAUGHTMAN'S TEXTBOOK.
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24. PRESS DIE DESIGN & CONSTRUCTION, PART I.
24a. PRESS DIE DESIGN & CONSTRUCTION, PART II.
25. TAPER CALCULATION & INSPECTION.
26. HEAT TREATMENT FUNDAMENTALS.
26a. HEAT TREATMENT EQUIPMENT.
26b. HEAT TREATMENT PRACTICE.
27. COMPOUND CHANGE GEAR PROBLEMS & INDEXING.
28. ELECTRONIC FUNDAMENTALS.
28a. ELECTRONIC APPLICATIONS.
29. MILLING CUTTER PRODUCTION & CALCULATION.
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34a. SHELL MOULDING, PART II.
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